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October 8, 2018

VIA EMAIL: VWsettle@tceq.texas.gov.

Re: Volkswagen Environmental Mitigation Trust Draft Beneficiary Mitigation Plan for Texas[1].

Public Citizen appreciates the opportunity to provide these comments. We would welcome the opportunity to discuss our recommendations further. Please contact Adrian Shelley at ashelley@citizen.org, 512-477-1155.

Before commenting we would like to thank TCEQ and its staff for the extensive work in developing the draft plan. We strongly support TCEQ's work to reduce emissions in an effort to mitigate the extra pollution caused by VWs non-compliant vehicles and dishonest gaming of vehicle emissions testing. We are also in strongly support of the Settlement Trust's objective of accelerating the deployment of heavy duty electric vehicles in the state.

I. TCEQ should better explain its by-area allocation of funding.

The reasons stated in the draft plan by-area allocation of 81% of the VW funding are inadequate and, we believe, do not explain the actual rationale for the decision. TCEQ has defined impacted communities as follows, "Those communities most impacted are those that likely had additional emissions from the vehicles under the consent decree that are measuring levels at or above the National Ambient Air Quality Standard for ozone." TCEQ gave lengthy explanations why certain areas were funded, relying in part on historical trends in ozone and ozone precursors.[2]

The VW Trust Agreement states that funding, "is intended to fully mitigate the total, lifetime excess NOx emissions from the Subject Vehicles where the Subject Vehicles were, are, or will be operated[.]" TCEQ's rationale is deficient in that it completely ignores the location of subject vehicles. TCEQ asserts that vehicle sales records provide an incomplete picture of where vehicles are operated today. This may be true, but it is reasonable to assume a similar distribution today as that indicated by sales records. TCEQ's by-area allocations suggest a different, unknown motive.

If TCEQ were basing its decision on ozone nonattainment status, it would have reached a different outcome. These are the 2015-2017 ozone design values for areas across the state[3]:

Area	2015-2017 Design Value
Houston-the Woodlands-Sugarland MSA	81 ppb
Dallas-Fort Worth-Arlington	79 ppb
San Antonio-New Braunfels MSA	74 ppb
El Paso MSA	71 ppb

[1] Draft Plan at vi.
[2] Trust Agreement at 1.
[3] *See* https://www.epa.gov/air-trends/air-quality-design-values.

Austin-Round Rock MSA	69 ppb
Killeen-Temple MSA	69 ppb
Beaumont-Port Arthur MSA	67 ppb
Amarillo MSA	65 ppb
Longview MSA	65 ppb
Victoria MSA	65 ppb
Tyler MSA	64 ppb
Corsicana MSA	63 ppb
Brewster County	62 ppb
Corpus Christi MSA	62 ppb
Marshall MSA	61 ppb
Polk County	60 ppb
Brownsville-Harlingen MSA	57 ppb
McAllen-Edinburg-Mission MSA	55 ppb

The Austin-Round Rock area was not included in the draft plan for funding, despite the fact that it has a higher design value than the Beaumont-Port Arthur area. The Austin-Round Rock area also has more affected vehicles registered per capita, at 2.39 affected vehicles per 1,000 people, than any other area in the state.

Because the stated rationale does not agree with the data, and because other potential motives might not be within the bounds of the trust, TCEQ must either reallocate funds appropriately or articulate a valid rationale.

II. TCEQ should not allocate funds on a strictly first-come first-served basis.

We have previously commented that TCEQ should plan to spend VW funds throughout the ten-year life of the trust agreement, making some funds available in future years for new technologies that will become available over time. TCEQ replied that it intends to spend VW funds as quickly as possible in an effort to bring the state's ozone nonattainment regions into attainment as soon as possible. While we agree with the goal of reaching attainment, we believe that a strict first-come first-served allocation of funds will leave some better options on the table. TCEQ should balance this approach against an approach that funds the most beneficial proposals and that encourages emerging technologies. We have also previously commented that these funds can create economic opportunity in Texas, by for example encouraging clean-tech manufacturing in the state. But such projects might take time to propose and implement. TCEQ should balance its desire to allocate funds quickly with these other considerations.

III. TCEQ should increase the reimbursement to public and private entities for new vehicles from 60% to 80%.

The negotiators of VW settlement intended significant funds to be used to support the deployment of more heavy duty and medium duty electric vehicles. Electric vehicles will not only reduce nitrogen oxide pollution, they will have added benefits of reducing additional pollutants, reducing road noise and reducing operating costs to save Texas businesses money and help reduce local governments costs (ultimately reducing taxes). To this end, we implore TCEQ to raise the reimbursement percentages from 60% of the new vehicle costs (including charge infrastructure) to 80% for both public and private entities.

IV. Freight switchers, tows, and tug boats should be included in the draft plan.

TCEQ excluded from its draft plan projects involving freight switchers and tugs and tow vessels. The stated rationale was because, "[t]hese projects are routinely funded under the TERP, and the TERP program provides funding for a greater percentage of the costs of these projects. Also, because of the limited areas where these locomotive and tugs and tow vessels operate, providing the funding under this mitigation plan may have limited interest given the higher grant award funding available through the TERP program."[4]

In fact, locomotive and marine projects have historically been disfavored under TERP and were completely excluded from the FY2016 grant round.[5] From FY 2007 through FY 2013, the cost per ton of NOx reduced limit for locomotive and marine projects was $5,000, compared to $10,000 for all other projects. Beginning in FY 2015, the cost per ton requirement for locomotive and marine projects is $10,000, compared to $15,000 for all other projects. But in FY 2016 locomotive and marine projects were completely excluded from funding.[6]

Because funds available under the TERP program are extremely limited for freight switchers, tow and tug boats, we request that TCEQ make them be eligible for engine replacement/repower under the VW mitigation funding. Repowering engines of the tugs and tow boats and replacing switchers is one of the most cost-effective ways to reduce NOx emissions.

If TCEQ is concerned about the "limited area" of operation for this equipment, it can place conditions on equipment purchased with incentive funds. And concern about "limited interest" from applicants is misplaced--TCEQ should make all possible funding opportunities available and let applicants decide where their interests lie. To prejudge which projects might appeal to applicants is to limit the possible

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[4] Draft plan at vii-viii.
[5] "Texas Emissions Reduction Plan Biennial Report," TCEQ publication SFR-079/16 (Dec. 2016) at p. 4.
[6] *Id.*

outcomes before the program has even begun. Incentive programs are often praised for their ability to foster innovation or new approaches. Limiting the options available in the plan limits the opportunity for innovation.

In 2017, Public Citizen held four public meetings in the greater Houston and Dallas-Fort Worth areas (see attached 1 pager). Community members ranked their preference for projects. While buses and trucks were among the most preferred projects, many community members also commented that they wanted TCEQ to include the projects that would have the largest and most cost-effective emissions reductions.

V. DERA funding should be accepted and the DERA match option included in the plan.

In recent years, TCEQ has not accepted federal Diesel Emissions Reduction Act (DERA) funding. This is due in part to the fact that DERA had been undersubscribed in recent years, which is in turn due to the fact that the program requirements in Texas are outdated. TCEQ has stated in the draft plan that it would like VW funds to complement other available sources of funding such as TERP. DERA is another available source of funding, and if TCEQ wishes for its incentive programs to function well together and complement one another, then it should accept all available funds. TCEQ should update its DERA program and include the DERA match program in its VW plan.

VI. TCEQ should dedicate some funding for projects in low-income communities.

With lower income communities disproportionately affected by air pollution, we recommend that TCEQ prioritize its funding allocations and awards to vehicles and equipment that operate in these communities. We recommend that 25% of all funds be designated for projects in low-income communities. For the zero emissions vehicle program, we suggest projects at multi-family housing units. Other opportunities could include all-electric transit vehicles operated in low-income communities and electric school buses at low-income schools.

Because TCEQ is limited in its funding options by applications received, we also recommend the Commission conduct outreach to underserved communities about the opportunity to apply for funds and provide assistance with applications as needed. This kind of outreach would be an appropriate use of the overhead allocated through the settlement.

VII. TCEQ should acknowledge the impact to environmental justice communities and ensure that the plan equitably benefits these communities.

In the draft plan, TCEQ hints at the disproportionate impact to communities located near ports but ignores the fact that these are typically low-income communities of color--environmental justice communities. Specifically, TCEQ states about port facilities: "And many of these facilities are surrounded by communities where there is the potential for the public to be exposed to a higher concentration of pollutants emitted from older diesel engines operating at the facility."

TCEQ should acknowledge the disproportionate impact to environmental justice communities from air pollution, including pollution from ports. TCEQ should also strive to improve conditions in those communities, including by ensuring that some funding is dedicated to low-income communities (as we have recommended above).

VIII. TCEQ should use the AFLEET tool to quantify emissions reductions from onroad vehicle projects.

While TERP projects are frequently ranked and awarded based on certified engine emissions levels for credit or weight-of-evidence for the SIP. Formal SIP credits are not needed from the VW funds. It is our understanding that the VW Funds should be maximizing emissions reductions and deployment of electric vehicles. We highly recommend that the TCEQ utilize the Argonne National Laboratory Alternative Fuel Life-Cycle Environment and Economic Transportation (AFLEET) Tool for quantification of all onroad vehicle projects. AFLEET includes adjustment factors for new diesel engines that reflect the higher emission rates at low speeds, based on the real-world research.

IX. Cost/Benefit Calculations should take into account the lifetime operation and maintenance cost of vehicles.

Some newer technologies, including all-electric vehicles, have higher initial costs. Today, an electric heavy-duty truck, for example, is more expensive to purchase than a "clean diesel" truck. But vehicles come with lifetime operation and maintenance costs that can tip the scales in favor of electric vehicles. See, for example, this lifetime cost analysis by J. Abrem with Columbia University, which account for purchase price, energy cost, and maintenance cost, and puts an electric bus at $1,180,000 lifetime (12 years) operation cost versus $1,348,000 for a diesel bus.[7]

X. We affirm comments by TxETRA regarding locations for EV charging stations.

The Texas Electric Transportation Resources Alliance (TxETRA) is preparing comments with recommendations for electric vehicle charger locations throughout the state. Public Citizen is a close partner of TxETRA and affirms that organization's comments regarding the placement of electric vehicle charging stations.

XI. A study by the University of Houston quantifies the potential impacts of vehicle turnover in the region.

Please find attached to these comments a draft report by Dr. Yunsoo Choi and colleagues at the University of Houston, "Evaluation of the air quality impacts of newer technologies, emissions controls and fleet electrification in the Houston Metropolitan Area for the year 2040." This report quantifies the reduction in several pollutants in the Houston region that can be achieved with vehicle turnover. The report shows that replacement of older vehicles is the best strategy for reducing emissions. It also shows the positive effects of electrified vehicles. We are including this report to illustrate the importance of funding projects in the Houston region.

Conclusion

Again, we appreciate the opportunity to provide these comments. If you wish to discuss the issues raised, please contact Adrian Shelley at

Respectfully,

Adrian Shelley
Director, Public Citizen's Texas Office

Enclosures: PDF, "VW Summary of Citizen Comments," a digest of comments Public Citizen received during the public meetings it held on the Volkswagen settlement.

Draft copy of "Evaluation of the air quality impacts of newer technologies, emissions controls and fleet electrification in the Houston Metropolitan Area for the year 2040" by the University of Houston for the Healthy Port Communities Coalition and the Public Citizen Foundation.

[7] See Abrem, J, "Electric Bus Analysis for New York City Transit," Columbia University (May 2016), available at http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf.

VW SETTLEMENT

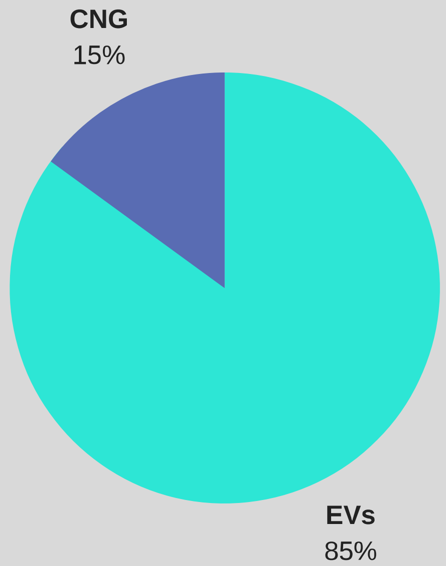
Community Engagement Summary

Volkswagen's emissions cheating scandal that created NOx pollution up to 40 times higher than allowed harmed public health and led to a $14.7 billion settlement. Texas will receive ~$209 million as part of the environmental mitigation trust. In the summer of 2017, we held meetings in Houston, The Woodlands, Dallas, and Fort Worth to inform community members about the VW Settlement and solicit community input on environmental mitigation projects. These four meetings had over 150 attendees in total.

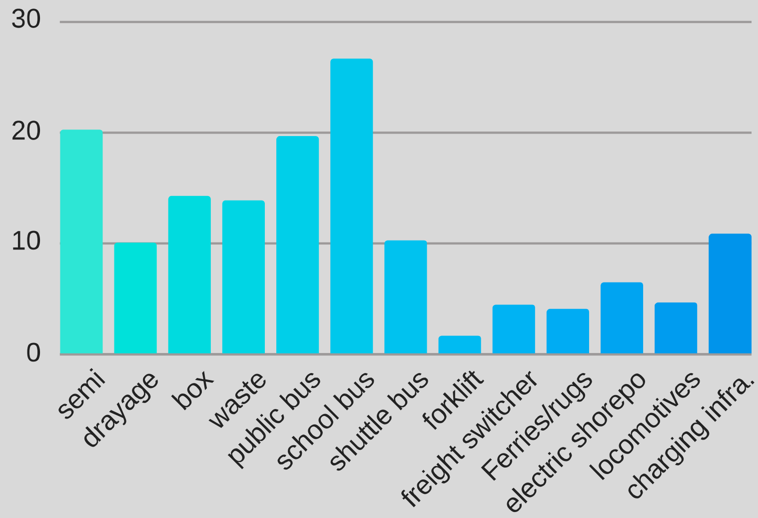
The State of Texas has not yet held public meetings regarding the settlement. Public Citizen alongside t.e.j.a.s., Air Alliance Houston, Coalition of Community Organizations, Sierra Club, Liveable Arlington, Tarrant Coalition for Environmental Awareness, and Arlington Conservation Council stepped in to gather important feedback from the community. Thanks to NCTCOG, HGAC, Port Houston, Centerpoint, and other TCAWG members for supporting this effort.

Community members largely support EV technology (85%) over CNG (15%) to diesel (0%). Community members favor projects that focus on school buses, semi-trucks, and public buses. Many expressed the sentiment that they would support the designated agency in supporting projects with the largest NOx emsissions reductions.

What fuel type do you support?



What types of projects do you most support?



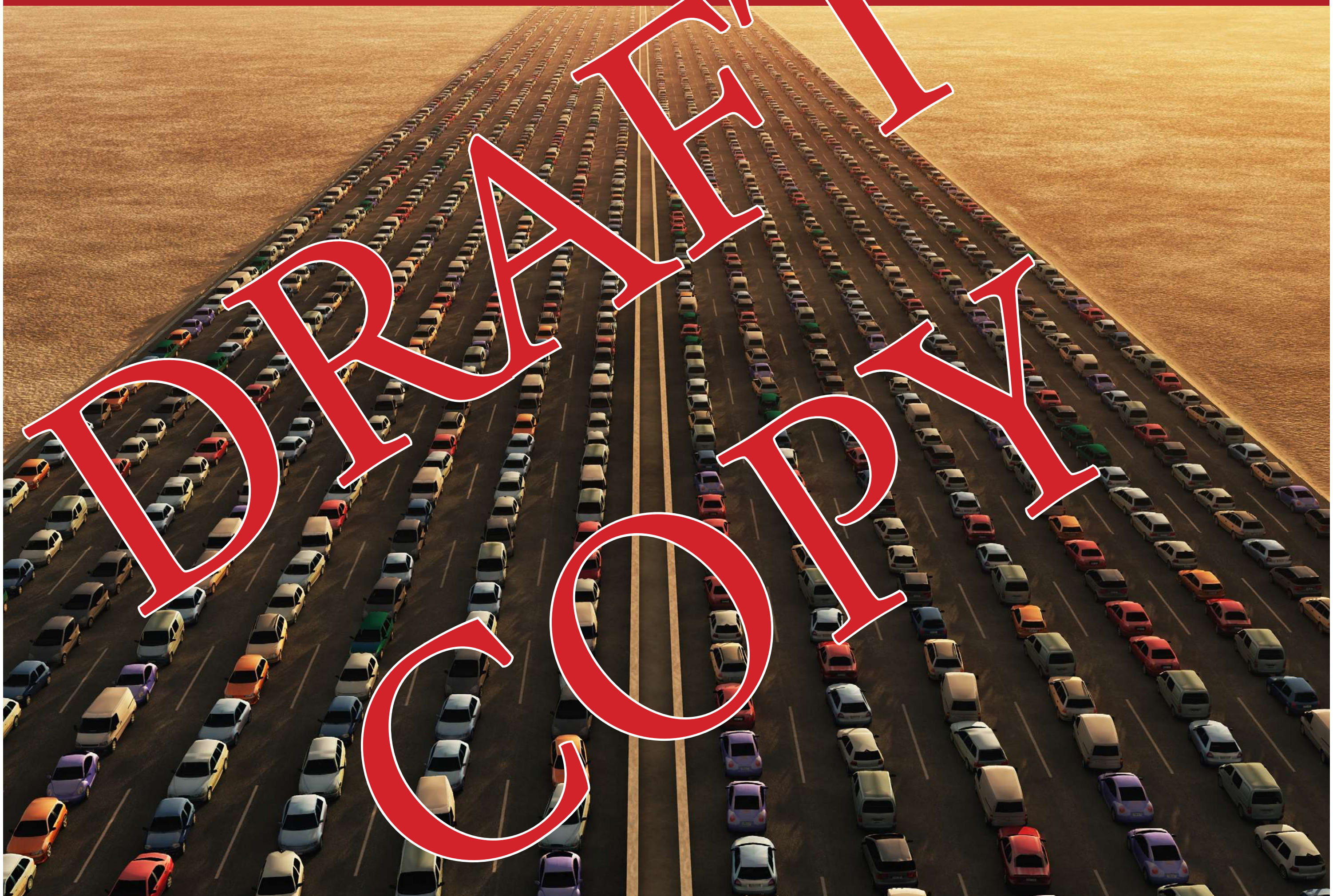


Community Feedback

Community Member suggestions:
- $$ should be used for whatever takes out the most NOX pollution; I leave that to those who have analyzed that data.
- Use funds for congestion mitigation at Port Houston based on real time remote sensing.
- Consider non-engine replacement projects such as: (1) NOx reducing engine catalysts, (2) projects that facilitate operational changes to reduce NOX (ship channel congestion, etc).
- The money should not go to private business interests' costs associated with modernizing their fleets.
- Expand electric vehicle infrastructure. Some of it should go toward implementing projects outlined in the Houston Bike Plan if deemed appropriate. Reducie the number of motorized vehicles on the road.
- In addition to trucks, also include gasoline vehicles and locomotives. Significant NOx reductions would mean we pay attention to gasoline emissions as well.
- The amount of diesel would be reduced (gallons not vehicles) with natural gas.
- Infrastructure: develop lots of EV charging stations nationwide to encourage travel.
- Tesla giga factory; toshiba - money in grants.
- None of the Settlement monies should be spent on any vehicle/equipment powered by CNG because in the Barnett Shale counties NOX emissions from O&G equal emissions from on road sources. Increased numbers of CNG vehicles would only worsen this problem.
- Create mass purchase day twice a year for TX municipalities; publish list 6 mos in advance.
- Electrify a "pilot set" of the pneumatic valves on gas wells. For example, one set of wells on land owned by a city that is leased to an oil/gas company.
- Maybe not VW but...battery powered lawn blowers and mowers. I'm hopeful that soon technology evolves to mow golf courses autonomously like the robovacuum.
- Do spot monitoring with penalties for nonconfoming vehicles. Tax rebates for updating commercial vehicles.
- Natural gas is too much water pollution.
- Grants to school districts to replace diesel buses.
- Grants for no idling campaigns.
- Garbage truck replacement (electric, CNG).
- Airport grants to electrify vehicles/equipment.

Community Member questions:
- How do different fuel types compare in terms of economics and environment?
Are funds available for research? If so, research ideas include: after-treatment systems to reduce NOx emissions, grid issues, replacing diesel engines with electric drive trains, other air quality monitoring issues.
- What is the m.o. of the funding award process, especially the ZEV program?
- What is the total emissions from coal plants and what can be done for TERP from those plant engines?
- This credit for buses is per county? How do cities qualify?
- More info from NTCOG for grants (cleanup) criteria.
- Why aren't point source compressors included? Diesel used in line compressors
- How would we get the knowledge back to our small counties?

UNIVERSITY of HOUSTON



Evaluation of the air quality impacts of newer technologies, emissions controls and fleet electrification in the Houston Metropolitan Area for the year 2040

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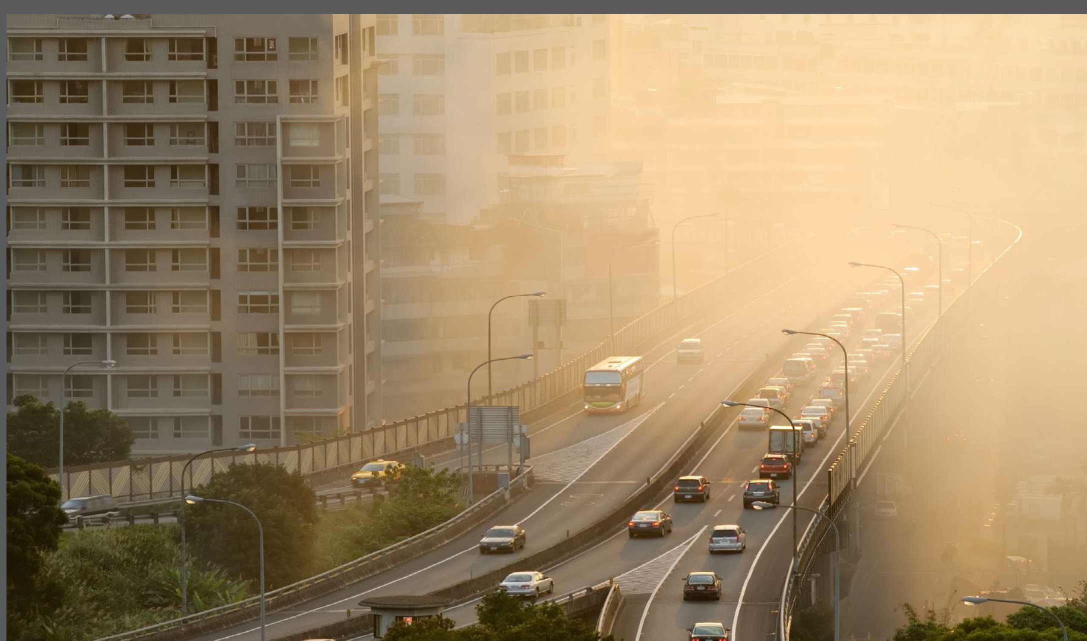
EXECUTIVE SUMMARY

Transportation is a major source of air pollution in the Houston Metropolitan Area and the 8-county region surrounding it (Harris, Chambers, Liberty, and Montgomery, Waller, Fort Bend, Brazoria, and Galveston counties, collectively referred to as "the region"). Transportation-related pollution is predicted to worsen with growing population and regional port expansion, with onroad vehicle traffic predicted to increase by 30%-80% by 2040. Control strategies to mitigate pollution include improved combustion technologies, tailpipe emissions controls, and fleet electrification. Regulatory Impact Assessments of these strategies often include only short-term projections. This report provides a detailed Regulatory Impact Assessment in 2040 to understand how significant implementation of multiple stringent emission control strategies would help improve air quality in the region. The data presented here demonstrate that implementing control strategies will decrease significantly both emergency room visits and mortality associated with exposure to ozone and particulate matter (PM2.5).

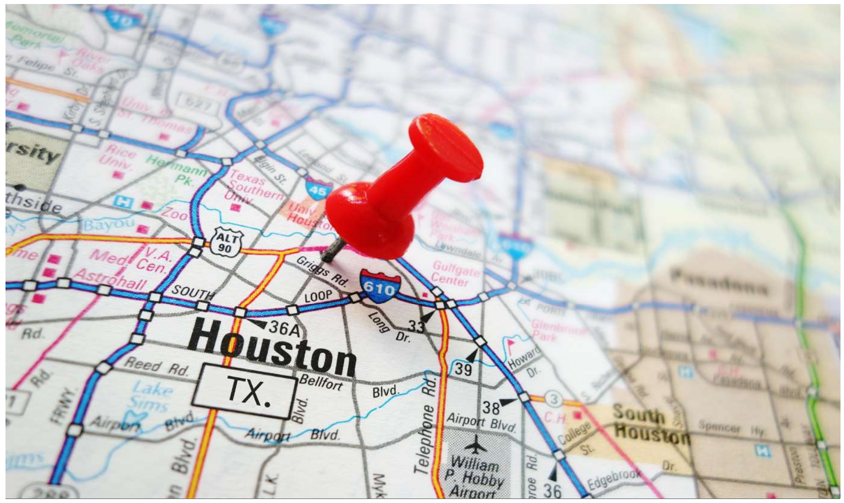
This study evaluates the effects of fleet electrification, replacement/retrofit with new combustion technologies/emissions controls on regional air quality and health. Four emissions control scenarios were modeled for aggregate emissions from gasoline and diesel vehicles, representing varying levels of fleet electrification and turnover to new technologies. In addition to emissions updates, appropriate scaling factors account for future increases in motor vehicle activity and population. A "Business-As-Usual (BAU)" scenario representing present day emissions and fleet composition with no turnover was modeled to demonstrate the impact of new technologies. In addition, three scenarios were considered to represent varying fleet turnover. These include Moderate Electrification (ME), Aggressive Electrification (AE), and Complete Turnover (CT). The ME scenario represents 35% and 33% fleet turnovers for electric and clean combustion technologies, respectively. The AE scenario represents 70% electric and 15% clean combustion technologies, while the CT case has 65% clean combustion and 35% electric respectively. The power generation inventory was updated for 2040 to account for retirement in regional fossil fuel capacity. A 1-km grid was used for air quality modeling to understand the impacts of these various emissions scenarios. The relatively fine-grid size illustrates the atmospheric chemistry processes in greater detail than previous modeling approaches.

In the BAU case, concentrations of nitrogen oxides, a key ozone precursor emitted by transportation, increased over Interstate 610, decreasing ozone concentrations over the highways because nitrogen oxides and ozone concentrations are inversely related in urban regions. However, the BAU case predicted significant ozone formation downwind where nitrogen oxides are the primary driver for ozone. Hence, the emissions control scenarios (ME, AE, CT) in which nitrogen oxides are reduced showed an increase in ozone concentrations over the highways and a significant reduction in ozone inside the I-610 loop and downwind. This is important because most housing communities are located in downwind areas and also in areas enclosed by the I-610 loop. Therefore, a reduction in nitrogen oxides and consequently, ozone will be beneficial to these communities.

The modeled emission reduction scenarios (ME, AE, CT) demonstrate a reduction in carbonaceous (organic and black carbon) particulate matter along highways. All 2040 projections show a near-total elimination of sulfate hot spots corresponding to the retirement of coal-fired electricity generation over the region. Investigation of health endpoints indicate an uptick in mortality and morbidity cases for the BAU emissions case, but significant decreases in mortality and morbidity for the ME, AE and CT scenarios. This study demonstrates that fleet electrification and new technologies can improve regional air quality and human health endpoints. It provides an incentive for continuing research on the air quality impacts of truck and bus stop electrification in the Houston region.



BACKGROUND



The 2010 US Census ranked Houston as the 4th largest city nationally. The United States Environmental Protection Agency classifies Houston as a nonattainment area for ozone and as borderline attainment for fine particulate matter (PM2.5) as indicated by EPA's Green Book (https://www.epa.gov/green-book). The ozone nonattainment area includes city of Houston, in Harris County, as well as the bordering counties of Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller. Identifying the sources of particulate matter and ozone-forming pollutants is imperative in order to develop appropriate control policy to improve air quality and health endpoints within the region.

Given the region's urban nature, emissions from transportation serve as major sources of nitrogen oxides (NOx) and volatile organic compounds (VOCs). These compounds react in the presence of sunlight to form ozone. In addition to ozone precursors, vehicular traffic also emits particulate matter pollution like organic and elemental carbon (Roy et al., 2016; May et al., 2013a, b; Gordon et al., 2013; George et al., 2014, 2015).

Gasoline motor vehicles and diesel trucks dominate urban transportation in the United States. The 2013 H-GAC Regional Goods Movement Plan indicates that the population of the region is projected to grow by 50% in 2040 to 9.6 million, which will almost certainly result in increased motor vehicle activity. A couple of studies have been conducted to project future vehicular activity. A study by the Texas Transportation Institute projects the number of trucks in the 8-county area to increase by 40%-80% (TCEQ, 2015), and number of gasoline vehicles to increase by 30-50% by 2040. This study provides a forward-looking analysis to evaluate the air quality impacts of increased transportation activity, the effects of control technologies and strategies, and the corresponding impact of the studied parameters on health endpoints.

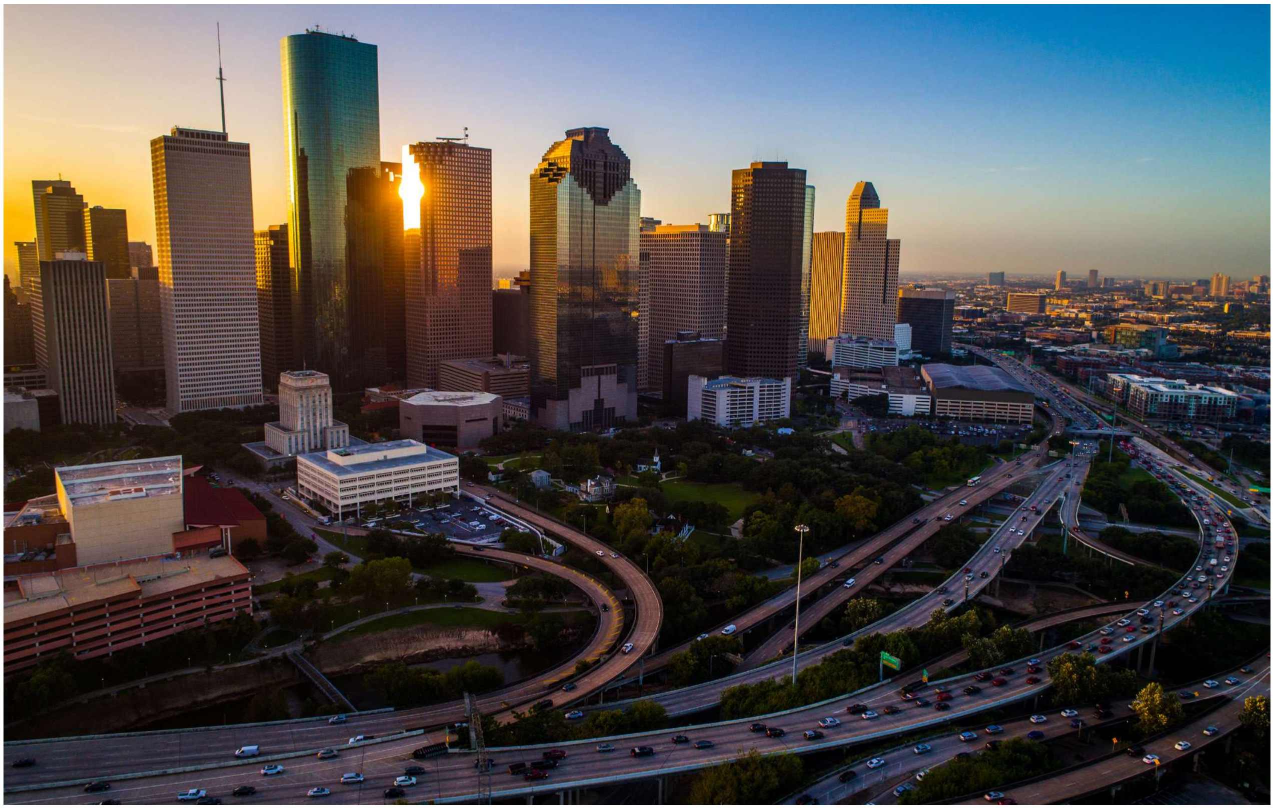
Several strategies exist to offset air quality impacts of increased transportation activity. Among them, accelerated fleet turnover is most well-known and implies a significant fraction of the motor vehicle fleet being replaced with newer technology to result in maximum emission reduction. These technologies include Gasoline Direct Injection and tailpipe emission control systems such as Selective Catalytic Reduction (SCR) for NOx emissions from both gasoline and diesel vehicles, and Diesel Particulate Filter (DPF) and Diesel Oxidation Catalysts (DOC) for PM2.5 and VOC emissions from diesel vehicles. Another alternative to reduce emissions is fleet electrification, the replacement of a certain fraction of the fleet with electric vehicles. Adding more electric vehicles into the fleet invariably results in an additional load on power generating infrastructure.

MOTIVATION

The effects of alternative strategies to reduce motor vehicle emissions needs to be investigated thoroughly using a Regulatory Impact Assessment framework. Such steps are usually taken by the United States Environmental Protection Agency (USEPA) whenever a new control rule is promulgated. The purpose of such studies is to consider the impacts of new control technologies and strategies on emissions in an air quality model to understand their effects and, using a health-effects model, to understand how the stricter standards or reduced emissions affect health endpoints. This is necessary since cleaner air will reduce mortality, morbidity, asthma cases and hospital visits (USEPA, 2017b). Examples of these sorts of investigations include the Cross-State Air Pollution Rule, CSAPR (USEPA, 2015) and the National Ambient Air Quality Standards for PM2.5 (USEPA, 2015). However, most of these analyses look only over a 10-year horizon. The Energy Information Administration (EIA)'s Annual Energy Outlook projects fuel consumption and other activity parameters far into the future, but do not account for emissions, their air quality impacts and changes in human health endpoints. Projections into a far-off year, such as 2040, can help understand the impacts of significant turnover in fleet composition and their effects on emission reduction, air quality and human health.

Most urban regions are typically VOC-limited, where ozone concentrations are primarily driven by VOC emissions. However, the Houston region has a unique distinction nationally by comprising both NOx and VOC-limited areas (Choi et al., 2012). Reducing only gasoline or diesel emissions may not be adequate to solve the problem of ozone pollution in Houston because the partial reduction of NOx emissions in many places can cause ozone concentrations to increase due to their NOx-saturated character. Therefore, we would need to account for substantial reductions in NOx emissions from both gasoline and diesel transportation sources to make the region NOx-limited, so that controlling NOx emissions can reduce ozone across the area.

Understanding ozone drivers over an urban region which has both NOx- and VOC-limited areas entails the use of fine resolution (~ 1 km) modeling. In a previous study (Pan et al., 2017b), we developed and evaluated a fine-resolution model to understand ozone concentrations and its key drivers over Houston for September 2013.



In this study, we extend the framework to understand motor vehicle emissions, fleet electrification and control strategies, and their associated air quality and health impacts.

In this space, this study executed the following tasks:

(1) Developed emissions scenarios for gasoline and diesel vehicles, corresponding to varying degrees of emission control, fleet electrification and fleet turnover.

(2) Implemented these emissions scenarios in a chemical transport model to understand their impacts on regional ozone and PM2.5, including its speciated components such as sulfate, nitrate, elemental and organic carbon. Calculated the change in concentrations of these species with respect to the base year of 2013 for each scenario.

(3) Calculated the changes in health endpoints for each scenario with respect to the base year.

METHODOLOGY

THE CHEMICAL TRANSPORT MODEL

The USEPA's Community Multiscale Air Quality (CMAQ) model (Byun and Schere, 2006) was used for this study. This is a chemical transport model which solves the continuity mass-balance equation, simulating the atmospheric processes of emission, advection, reaction, dry and wet deposition and chemistry for a given geographical region by discretizing the region into several horizontal, lateral and vertical grid cells. Our group has had extensive experience using this model, as is evident from several publications (e.g., Choi et al., 2009; Choi et al., 2010; Choi et al., 2012; Choi, 2014; Choi and Souri, 2015a, b; Czader et al., 2015a, b; Diao et al., 2016a, 2016b; Li et al., 2016; Pan et al., 2015, 2017a,b; Souri et al., 2016a, 2016b). We will be using a 1-km grid over the Houston area and surrounding counties, which include Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller.

THE METEOROLOGICAL MODEL

The Weather Research and Forecasting (WRF) model (Skamarock et al., 2008) provided meteorological fields for this study. We have evaluated existing analysis datasets and decided to use the National Centers for Environmental Prediction's (NCEP) North American Regional Reanalysis (NARR) as input. The NARR data are based on an NCEP Eta 221 regional North American grid (Lambert Conformal) (additional information is available here: http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html) at 29 pressure levels. Its horizontal resolution is 32-km, and the frequency is 3-hourly.

THE EMISSIONS MODEL

The USEPA's National Emissions Inventory of 2011 (NEI2011) was processed using the USEPA's Sparse Matrix Operator Kernel Emissions (SMOKE) model (Houyoux et al., 2000), to produce model-ready emissions. SMOKE performs gridding, temporal allocation, and speciation lumping for a given chemical mechanism to prepare model-ready emissions. Additional details are online: https://www.cmascenter.org/smoke/. The procedures for this study involved merging the updated gasoline and diesel motor vehicle emissions from the Motor Vehicle Emissions Simulator (MOVES) model (USEPA, 2017a) into the base emissions inventory.

THE MOTOR VEHICLE EMISSIONS MODEL

This study used the USEPA's Motor Vehicle Emissions Simulator (MOVES) model (USEPA, 2017a), which calculates emissions from gasoline and diesel on-road vehicles as a function of speed, road type, and meteorological conditions. The model is instrumented to change motor vehicle population (VPOP) and vehicle miles traveled (VMT) for a future year, which we used to make projections for 2040. For this study, emissions from gasoline and diesel vehicles for the 8-county area were modeled. The emissions comprise of multiple modes. Rates per distance typically represent tailpipe (exhaust) emissions, while rates per vehicle represent evaporative and crankcase emissions. In addition, truck drivers often spend the night inside the vehicle's cabin, where the air conditioning is powered by the truck engine. This phenomenon is called hoteling and can give rise to significant nighttime emissions.

EMISSIONS CONTROLS AND FLEET TURNOVER

Fleet-average emissions are a function of (a) percentage reduction brought about by new controls and (b) fleet turnover which corresponds to the fraction of the fleet fitted with these new controls (typically newer vehicles/engines), represented as:

$$EF_i(2040) = EF_i(2013)[f_{replaced}(1 - f_{control}) + 1 - f_{replaced}] \quad (1)$$

Where $EF_i(2040)$ and $EF_i(2013)$ are the projected fleet-average emission factors for 2040 (future year) and 2013 (base year), respectively; $f_{\mathbf{control}}$ represents the percentage reduction due to a control technology, while $f_{\mathbf{replaced}}$ represents the fraction of the fleet that has been replaced or fitted with the new control technology, typically referred to as "fleet turnover". Examples of tailpipe emissions control technologies for NOx emissions include Selective Catalytic Reduction and NOx absorbers. Diesel Oxidation Catalysts reduce VOC emissions from diesel exhaust while Diesel Particulate Filters (DPFs) reduce PM2.5 emissions. Evaporative emissions, typically reported per vehicle, result from fuel volatilization.

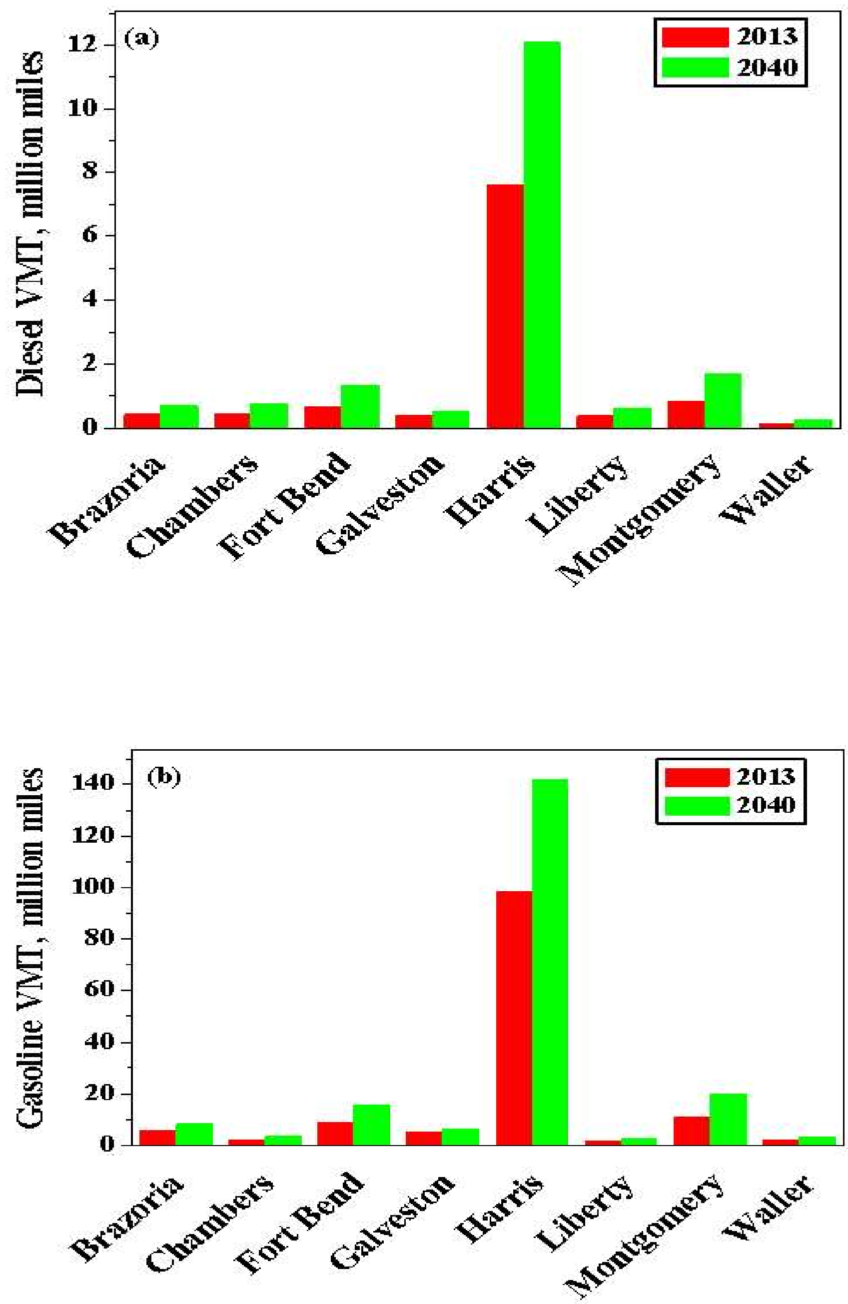


Figure 1: (a) Diesel and (b) gasoline vehicle miles travelled (VMT) projections. The scaling factors used in this study are the ratio of the 2040 and 2013 numbers.

FUTURE ACTIVITY PROJECTIONS

Projections for VPOP and VMT were taken from calculations performed by the Texas Transportation Institute (TTI) for the Texas Commission for Environmental Quality (TCEQ, 2015). The authors performed activity calculations from 1999, projected to 2050. The activity data for each vehicle type (e.g. gasoline passenger cars, pickup trucks, medium duty and heavy duty diesel trucks) were obtained through personal communication with Dennis Perkinson at TTI. Their findings project aggregate VMT to change by 30%-80% over the 8-county area. The aggregate activity was fractionated into 24 different gasoline and diesel vehicle types, from which two surrogate profiles for the 8-county area were developed, namely Houston and Beaumont. The gasoline-diesel split for VMT for the base year is 93%-7% for Houston and 82%-18% for Beaumont. The split changes marginally in favor of diesel in 2040, 92%-8% for Houston and 81%-19% for Beaumont. The higher diesel fraction over suburban Beaumont could be explained by the fact that diesel truck traffic is comparable across urban and suburban regions while gasoline activity is significantly higher in the urban, hence depressing the diesel fraction.

The Brazoria, Fort Bend, Galveston, Harris, Montgomery, and Waller counties were represented by Houston, while Chambers and Liberty were represented by Beaumont. These profiles were used to project gasoline and diesel VMTs in 2040, indicated in panels (a) and (b), with their specific scaling factors in (c). The projected gasoline VMTs are roughly one order of magnitude higher than diesel, due to the higher gasoline vehicles population. The gasoline and diesel projected scaling factors closely mirror the total VMT, indicating the change in VMT is more significant than that in the gasoline-diesel split. However, there is one subtle difference: the diesel scaling factor is slightly magnified, while the gasoline one is slightly depressed. For example in Harris County, the total VMT changes by a factor of 1.46, while the diesel VMT changes by 1.59 and gasoline by 1.45. This could be attributed to the marginal shift in favor of diesel (~9% increase). These VMT profiles were also used for county and fuel-specific vehicle population (VPOP) projections.

FUTURE MODELING SCENARIOS

Several emissions scenarios were considered to account for the uncertainty in fleet turnover and electrification. In Table 1, "Clean Combustion Technologies" indicates the percentage of the fleet in 2040 that uses or is retrofitted with state-of-the-art combustion and emission control technologies, "Electric" represents the percentage of the fleet comprising electric vehicles, while "Current" represents the fraction carrying over from the base year of 2013 that is not retrofitted or replaced. The scaling factor represents the bracketed term in Equation (1), which is a function of both control technology efficiency and fleet turnover, applied to aggregate (distance, vehicle and hoteling) gasoline and diesel emissions. Activities were scaled using county and fuel specific information from Figure 1. The same scaling factors were used for VMT and hoteling activity projections.

The Business As Usual (BAU) case represents a "worst case" scenario, with no new technology vehicles incorporated into the fleet or the existing fleet is not retrofitted. The Moderate Electrification case is based on the assumptions of a Bloomberg New Energy Finance report (BNEF, 2016), which predicted that 35% of global vehicles would be electric by 2040. The Aggressive Electrification (AE) case assumes a fraction twice that of the ME case. Complete Turnover (CT) represents a scenario where the total fleet comprises either of state of the art technology or electric vehicles.

Table 1: Future projects scenarios based on varying fleet electrfication and turnover.

Percentage Fleet Turnover			
Scenario	**Clean Combustion Technologies**	**Electric**	**Current**
Base-year (2013 or BASE)	0	0	100
Business as usual (BAU)	0	0	100
Moderate Electrification (ME)	33	35	32
Aggressive Electrification (AE)	15	70	15
Complete Turnover (CT)	65	35	0

PROJECTED SCENARIOS BASED ON VARYING FLEET ELECTRIFICATION AND TURNOVER

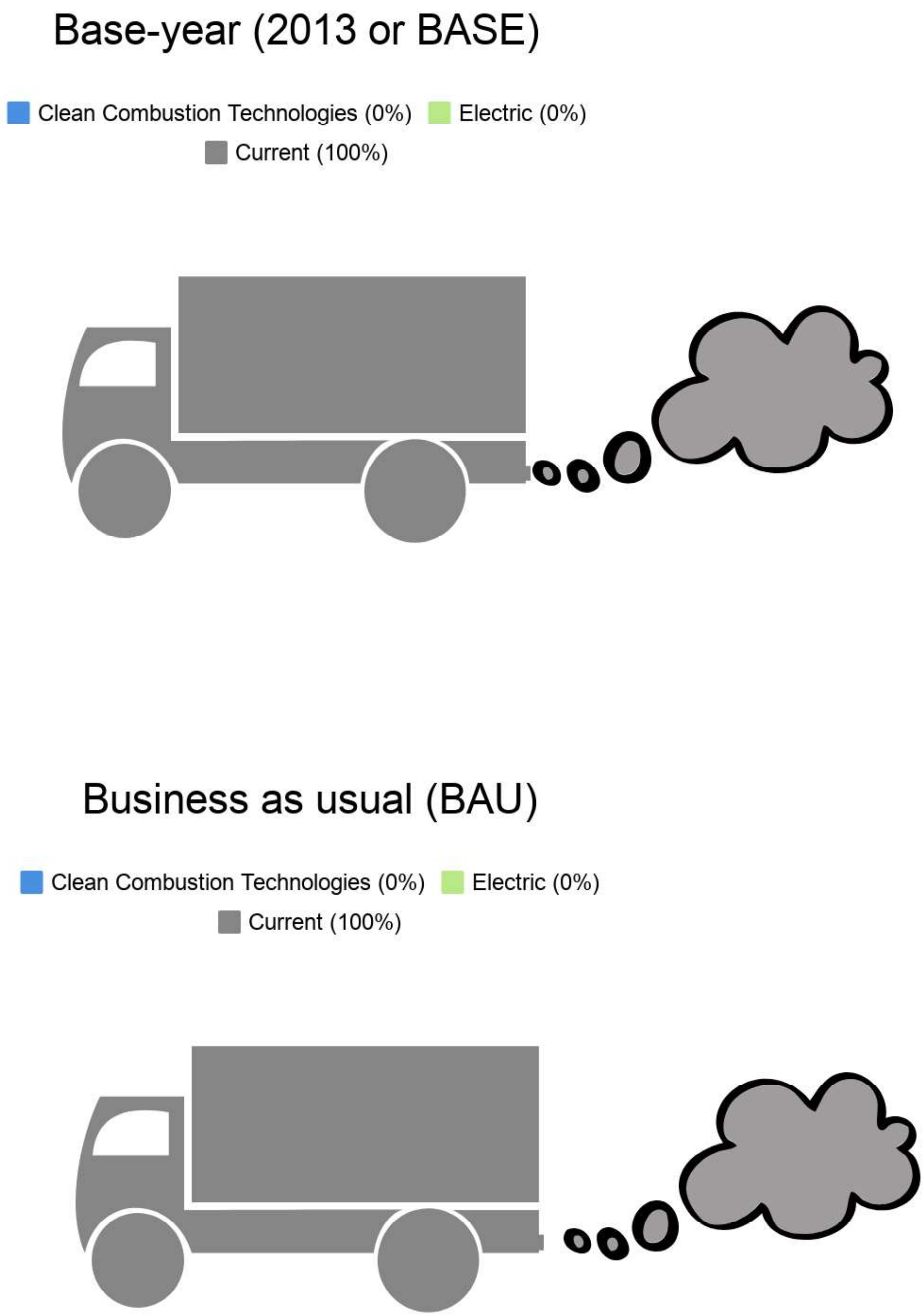


Figure 2: Emissions factor in each case.

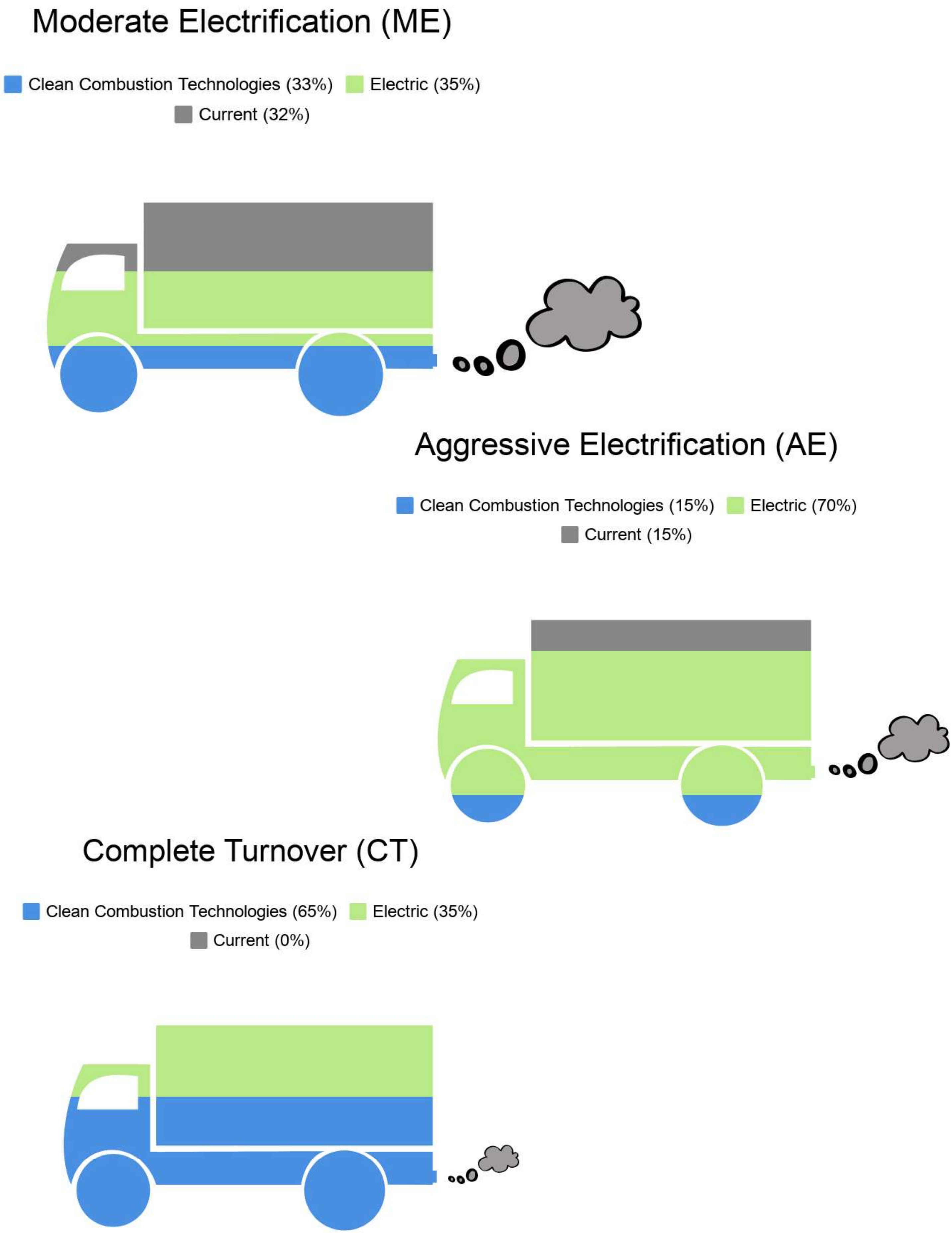


Figure 2: Emissions factor in each case.

ELECTRICITY LOAD DUE TO MOTOR VEHICLE ELECTRIFICATION

The added electricity required to power the motor vehicle fleet could potentially result in increased emissions from Electricity Generating Units (EGUs). However, several projections from the Electricity Reliability Council of Texas (ERCOT) (Borkar et al., 2016) have indicated that the projected electricity generation in 2040 will be in western Texas, resulting in no new emissions in the 8-county area. An example of the projected siting from the Business As Usual ERCOT scenario is shown in Figure 2; this scenario was used for the current study. The ERCOT projections indicate significant retirement of fossil-fired capacity in 2031 for southeastern Texas. We added no future capacity in our simulations but needed to account for capacity downsizing in order to represent a more realistic scenario in 2040.

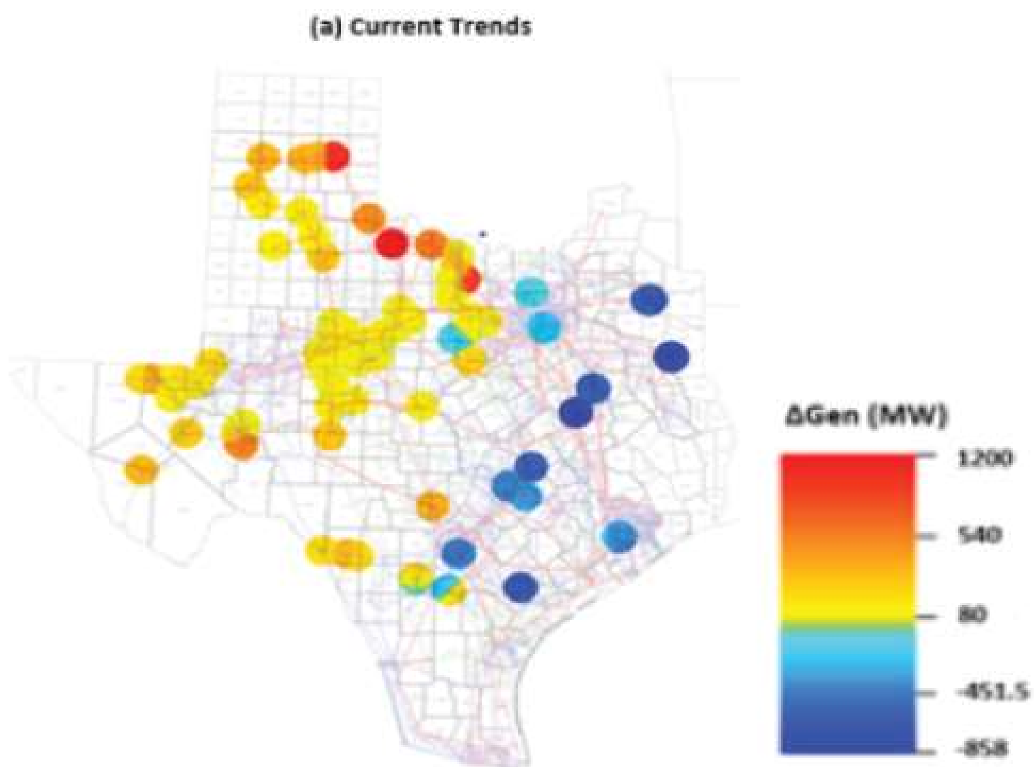
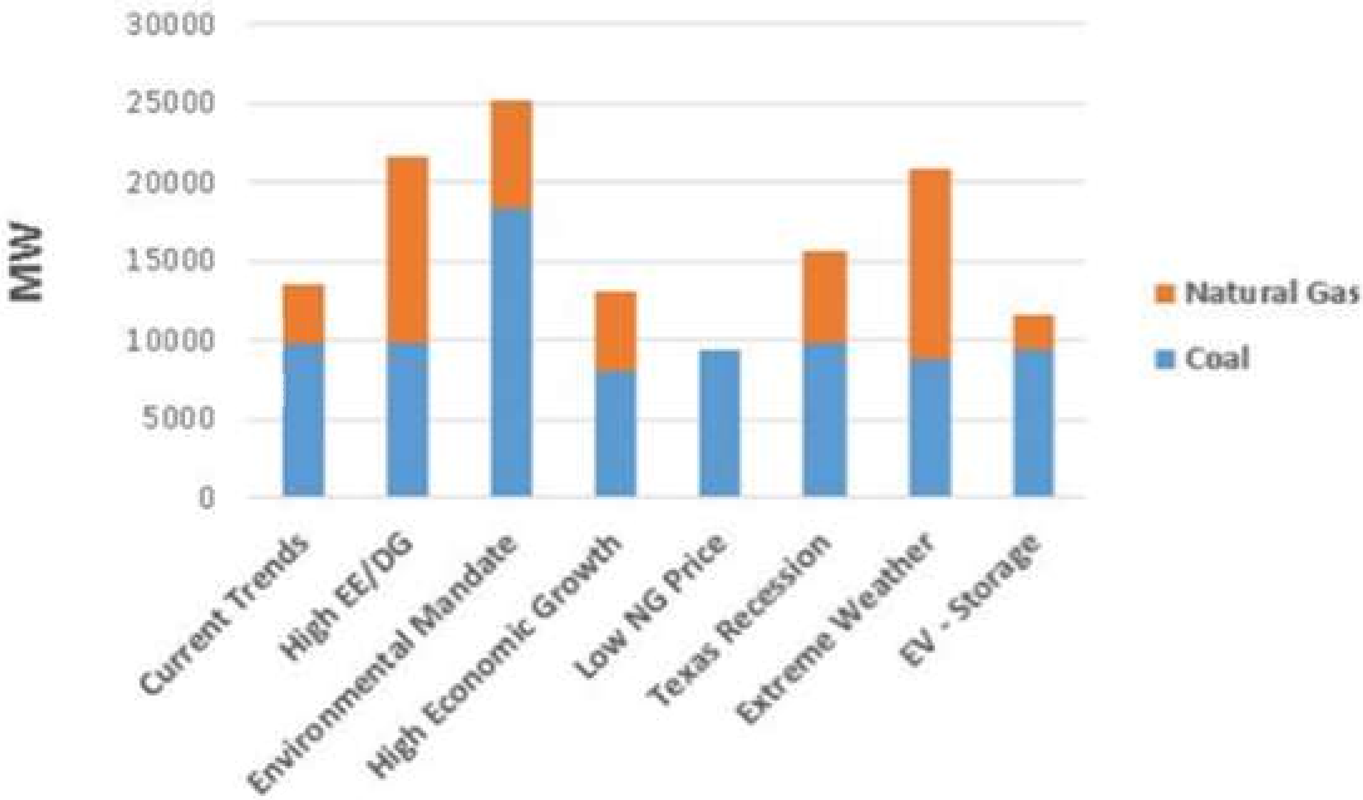


Figure 3: Map of generation capacity retirement across Texas in 2031 for ERCOT's Current Trends scenario (above), and capacity retirements for coal and natural gas for all of ERCOT's modeled scenarios (next page).



Future electricity capacity was estimated by assuming a linear decline in coal and gas generation over the 8-county area. For example, Figure 3 (previous page) indicates that around 500 MW will cumulatively retire in 2031. The panel on this page indicates the ratio of coal retirements to that of gas being 3:1. In other words, the coal-gas split is 75%-25%. Applying this to the Current Trends case, 375 MW of coal and 125 MW of natural gas capacity will cumulatively be retired by 2031.

Assuming a linear decline rate (recommended by Warren Lasher, personal communication, 2017) starting from 2013, the rate of decline for coal capacity is 375/18 = 21 MW/yr. Similarly, the decline rate for natural gas is ~ 7 MW/yr. Multiplying these numbers by 27 years (2040-2013) provides the predicted number of cumulative retirements by 2040.

Hence, cumulative coal retirement in 2040 = 21x27 =567, ~ 600 MW.

Cumulative natural gas retirement in 2040 = 7x27 = 189, ~ 200 MW.

Scaling factor for coal = [Coal (2013)-600]/Coal (2013) = 0.89 (~ 11% decrease)

Scaling factor for natural gas = [NG (2013)-600]/NG (2013) = 0.99 (1% decrease).

THE HEALTH IMPACTS MODEL

The U.S. EPA Environmental Benefits Mapping and Analysis Program (BenMAP) Community Edition version 1.3 (U.S. EPA, 2017b) was used to estimate health impacts and corresponding economic costs for each future scenario. This is a Geographic Information Systems (GIS)-based model that estimates changes in the incidence of adverse health effects and associated monetary value due to changing ambient air pollution concentrations (Fann et al., 2012). The air quality inputs of the model include a baseline scenario (2013) and the four emission control scenarios (BAU, AE, ME, and CT in Table 1). The health impact calculations in BenMAP are based on Concentration-Response (C-R) functions, also known as health impact functions. These functions define a mathematical relationship relating a decrease in adverse health effects with a concentration of air pollutants. A commonly used type is the log-linear format:

$$\Delta y=(1-e^{(-\beta\cdot\Delta x)})\times y_0\times Pop \qquad (2)$$

where Δy represents the change in the incidence of adverse health effects, β the concentration-response coefficient, Δx change in air quality (e.g. O_3 concentrations), y_0 the baseline incidence rates, and Pop the affected population.

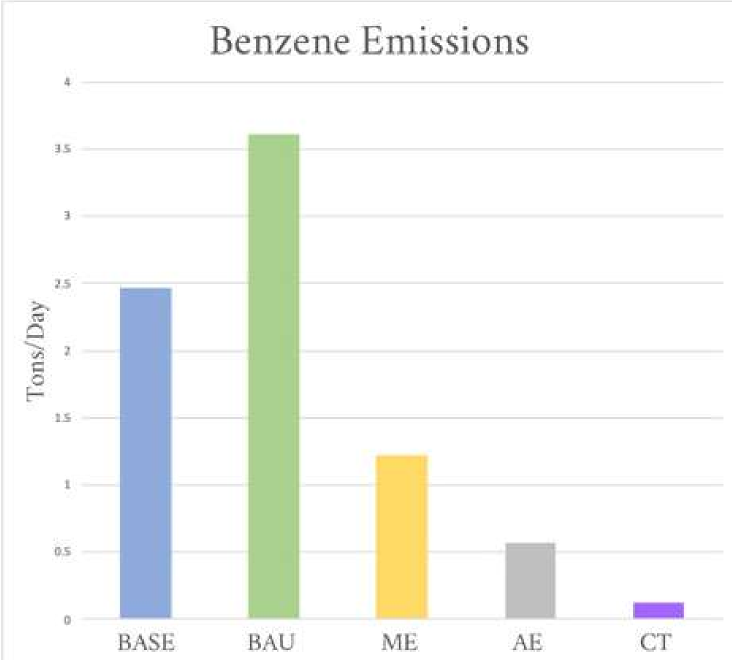
The relationship between changes in air pollutants concentrations and incidence of health outcome (i.e., β) have been assessed through several epidemiological studies. These studies have produced a number of C-R functions that have been incorporated into the BenMAP model. Additionally, the BenMAP model calculates the economic cost of avoided premature mortality using a "value of statistical life" (VSL) approach, which is the aggregate monetary value that a large group of people would be willing to pay to slightly reduce the risk of premature death in the population (U.S. EPA, 2017b). The economic costs for morbidities were estimated using the cost of illness, which includes direct medical costs and lost earnings associated with illness.

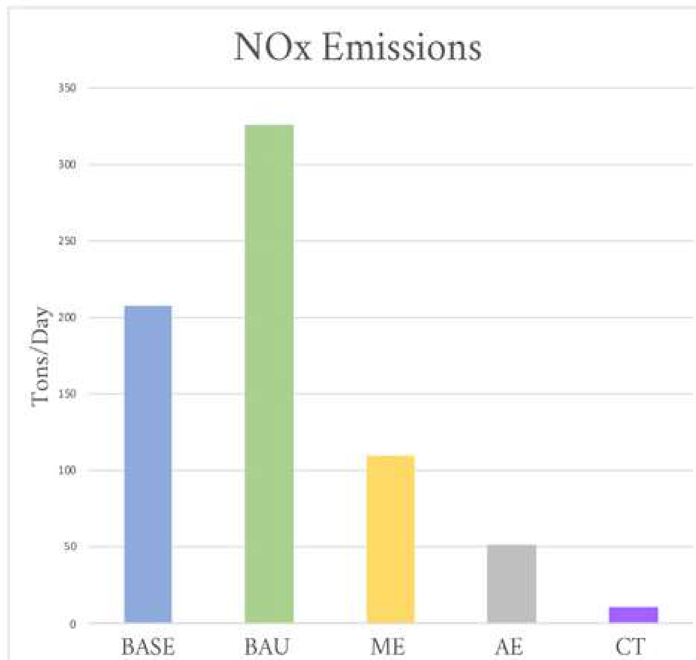
Table 2. Episode-average 8-county aggregate on-road mobile emissions in the BASE case and comparative changes for the future scenarios.

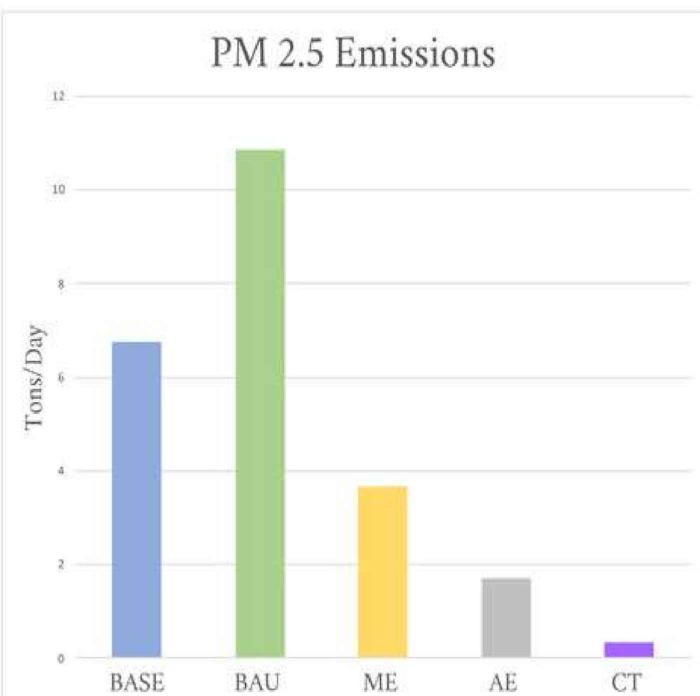
Species	BASE [tons/day]	Difference to BASE			
		Business as Usual (BAU) %	BAU [tons/day]	Moderate Electrification (ME) %	ME [tons/day]
CO	1220.64	48.6	1813.87	-50.0	610.32
NOx	207.51	56.9	325.58	-47.2	109.57
NH3	5.51	50.8	8.31	-49.2	2.80
SO2	1.69	50.9	2.55	-49.2	0.86
PM10	16.88	55.3	26.21	-47.7	8.83
PM2.5	6.75	61.1	10.87	-45.8	3.66
non-HAP TOGs	72.81	48.3	107.98	-50.1	36.33
Benzene	2.47	46.3	3.61	-50.8	1.22
Formaldehyde	1.66	60.5	2.66	-45.8	0.90
Acetaldehyde	1.15	54.3	1.77	-48.0	0.60
Acrolein	0.11	63.1	0.18	-45.1	0.06
1,3-butadiene	0.44	46.5	0.64	-50.7	0.22
Naphthalene	0.21	58.1	0.33	-46.8	0.11
N2O	3.19	44.5	4.61	-51.4	1.55
CO2	92967.76	52.4	141682.87	-48.7	47692.46
CH4	3.33	54.0	5.13	-46.8	1.77

Species	BASE [tons/day]	Difference to BASE			
		Aggressive Electrification (AE) %	AE. [tons/day]	Complete Turnover (CT) %	CT [tons/day]
CO	1220.64	-76.6	285.63	-95.2	58.59
NOx	207.51	-75.3	51.25	-94.9	10.58
NH3	5.51	-76.2	1.31	-95.1	0.27
SO2	1.69	-76.2	0.40	-95.1	0.08
PM10	16.88	-75.5	4.14	-94.9	0.86
PM2.5	6.75	-74.6	1.71	-94.8	0.35
non-HAP TOGs	72.81	-76.6	17.04	-95.2	3.49
Benzene	2.47	-77.0	0.57	-95.2	0.12
Formaldehyde	1.66	-74.5	0.42	-94.6	0.09
Acetaldehyde	1.15	-75.7	0.28	-94.9	0.06
Acrolein	0.11	-74.3	0.03	-94.7	0.01
1,3-butadiene	0.44	-76.9	0.10	-95.2	0.02
Naphthalene	0.21	-75.1	0.05	-94.9	0.01
N2O	3.19	-77.2	0.73	-95.3	0.15
CO2	92967.76	-76.0	22312.26	-95.0	4648.39
CH4	3.33	-73.9	0.87	-92.9	0.24

Figure 4: Visualizations of Table 2 emissions for selected pollutants: Benzene, PM 2.5, and NOx.







RESULTS:

EMISSION SCENARIOS AND CORRESPONDING CHANGES

Because the emissions inventories are "ground-zero" for a modeling study, comparison of pollutant emissions for each scenario provides insight into potential air quality changes. Table 2 (see page 21) compares projected emissions with the 2013 base case. The Business as Usual Case in 2040 exhibits significant increases in species emissions with respect to the 2013 base case due to the lack of control/retrofit imposition. The other cases show significant decreases in emissions, with 46%-51% for Moderate Electrification and above 93% for Complete Turnover, consistent with the assumptions used to develop these scenarios.

THE SIMULATION DOMAIN, EPISODE, AND MISCELLANEOUS DETAILS

The simulation domain comprises the 8-county area surrounding Houston at a 1-km resolution and is depicted in Figure 5. Simulations were run for September, using meteorology for 2013. Boundary conditions were obtained from a real-time air quality forecasting system over the United States using the above mentioned CMAQ model at a coarser 12 km resolution; additional details about this modeling system are online: http://spock.geosc.uh.edu.

Additionally, both VOC and PM2.5 emissions need to be speciated for use in the CMAQ model. This is because VOCs differ significantly in their formation to form ozone and secondary organic aerosol due to markedly different molecular structures (e.g. Carter, 1994; Presto et al., 2010; Tkacik et al., 2012, Roy et al., 2016). Additionally, PM2.5 comprises a large number of species with widely differing properties. For example, elemental carbon (EC) emissions from gasoline and diesel vehicles is a known global warming agent, while sulfate aerosol resulting from the chemistry of SO2 emissions acts to cool the atmosphere. The speciation was performed as per the Carbon Bond version 5 (CB05) chemistry mechanism (Yarwood et al., 2005), with speciation profiles being taken from the SPECIATE database (USEPA, 2016).

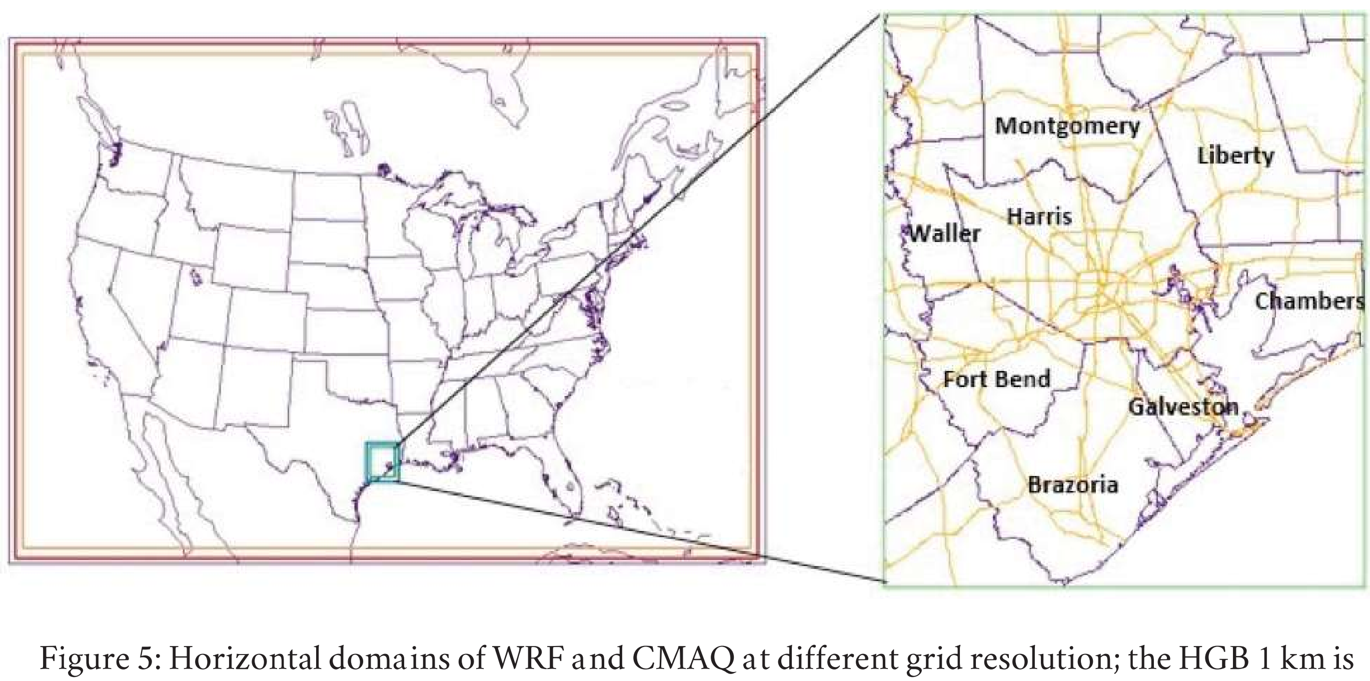


Figure 5: Horizontal domains of WRF and CMAQ at different grid resolution; the HGB 1 km is used in this study while the US 12 km is used to provide boundary conditions. For the zoomed-in plot on the right, roadways are represented in orange and county boundaries in purple.

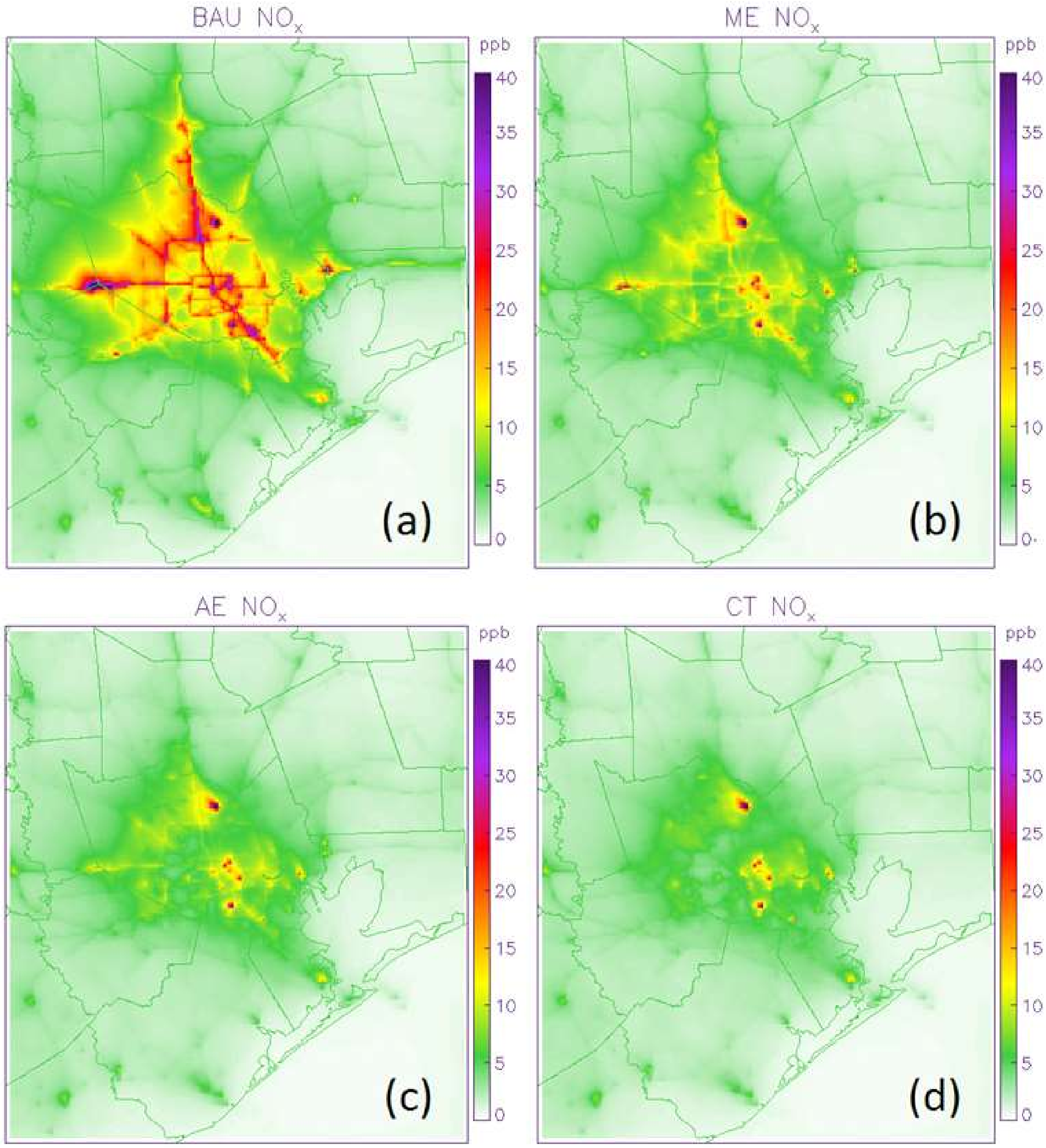


Figure 6: Simulated total NOx concentrations (parts per billion, ppb) for the year 2040 in each case: (a) BAU-Business As Usual, (b) ME – Moderate Electrification, (c) AE- Aggressive Electrification, and (d) CT – Complete Turnover.

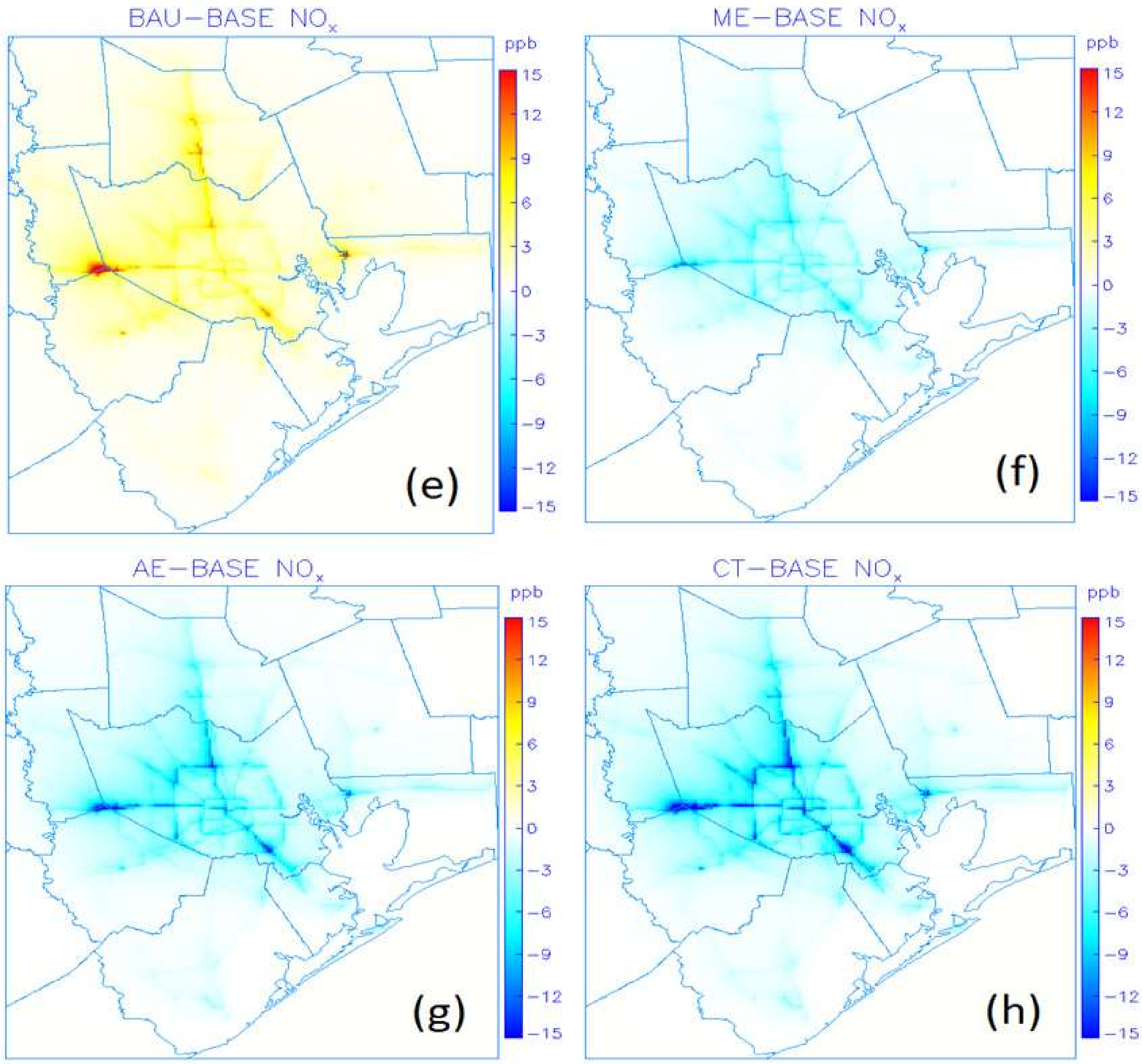


Figure 6: Simulated NOx concentration differences (parts per billion, ppb) from 2013 basline to each 2040 case: (e) BAU-Business As Usual, (f) ME – Moderate Electrification, (g) AE- Aggressive Electrification, and (h) CT – Complete Turnover.

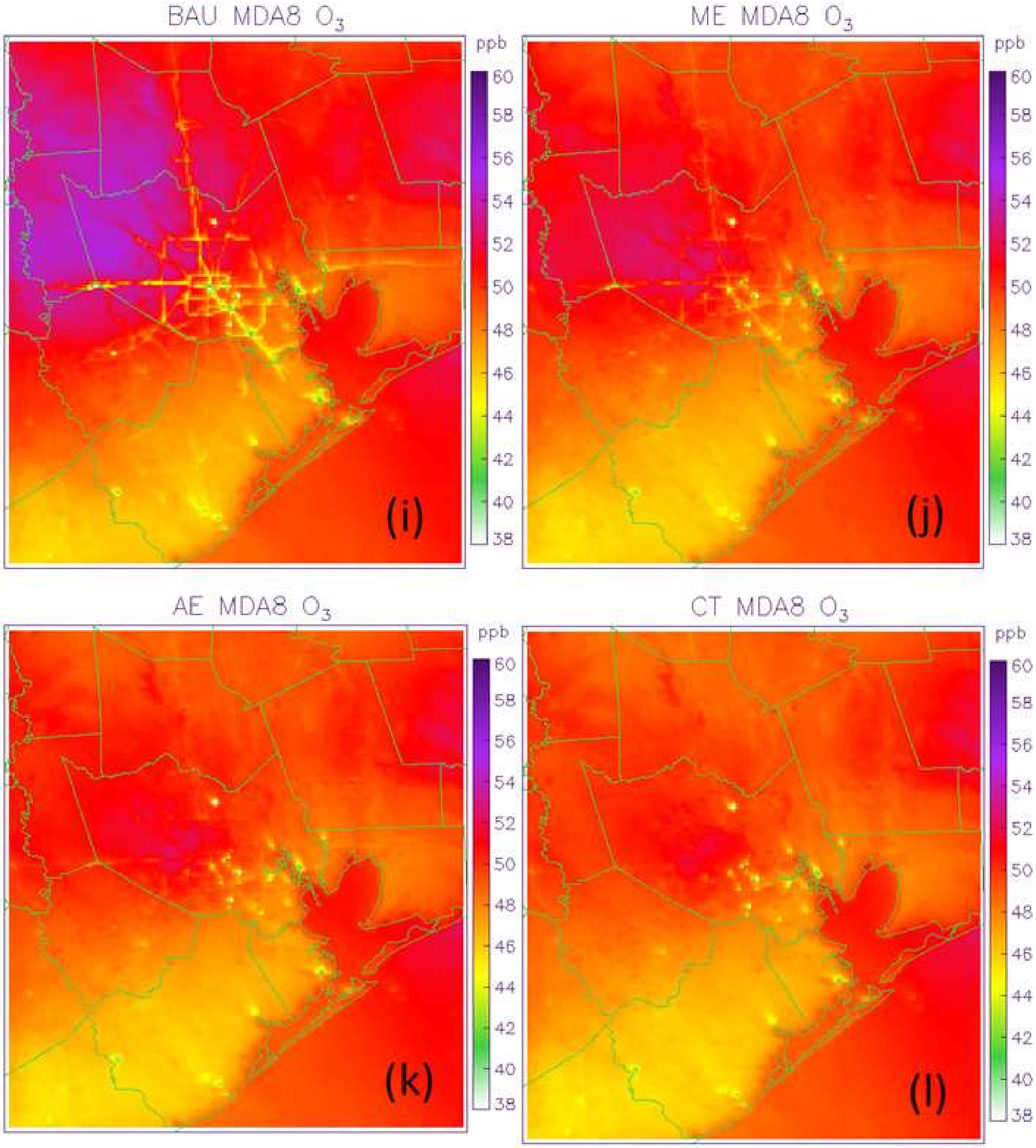


Figure 6: Simulated total Maximum Daily 8-hr Average (MDA8) ozone concentrations (parts per billion, ppb) for the year 2040 in each case: (i) BAU-Business As Usual, (j) ME – Moderate Electrification, (k) AE- Aggressive Electrification, and (l) CT – Complete Turnover.

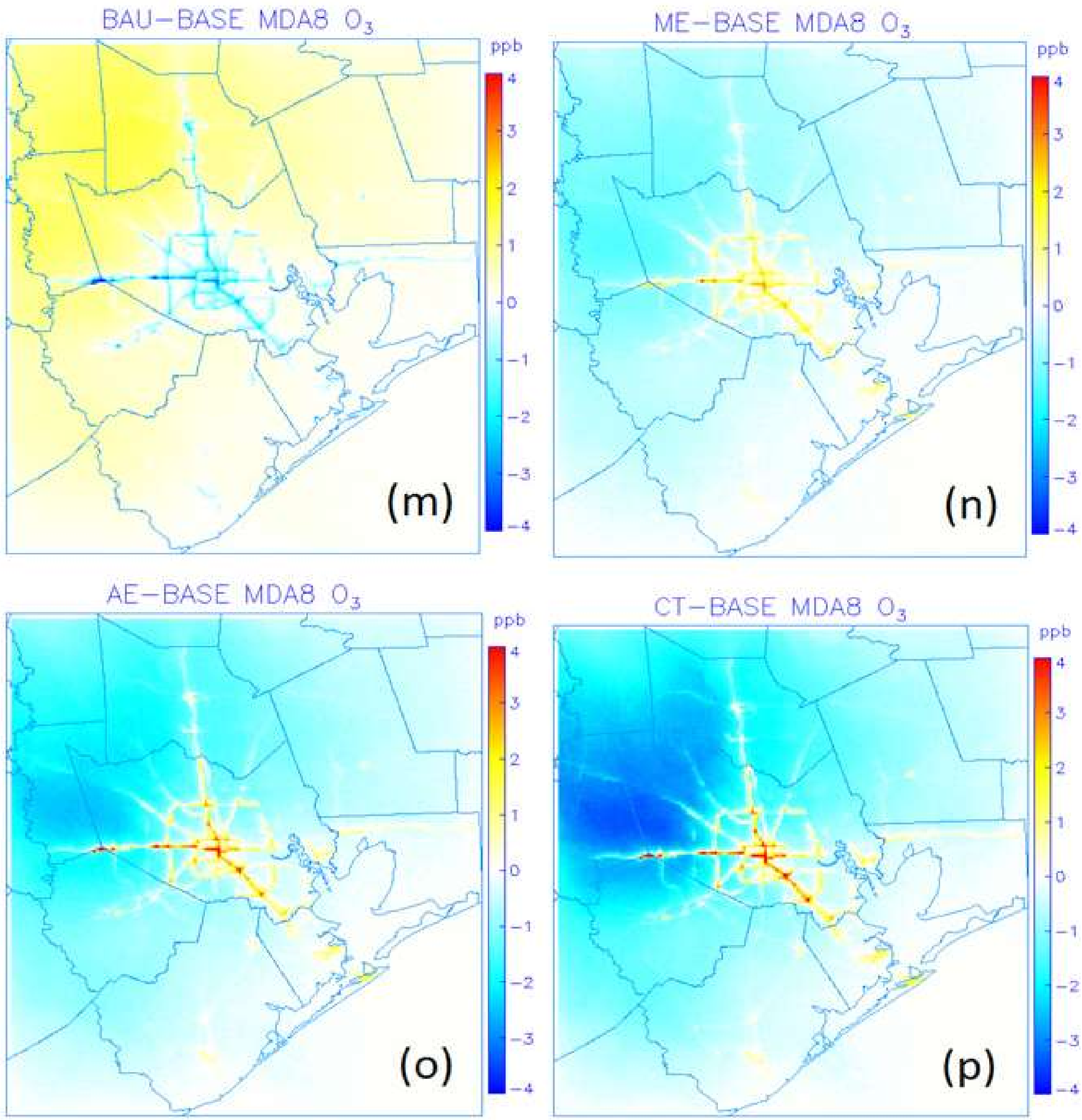


Figure 6: Simulated Maximum Daily 8-hr Average (MDA8) ozone concentration differences (parts per billion, ppb) from 2013 baseline to each 2040 case. (m) BAU-Business As Usual, (n) ME – Moderate Electrification, (o) AE- Aggressive Electrification, and (p) CT – Complete Turnover.

CMAQ SIMULATION RESULTS: OZONE AND NITROGEN OXIDES

Figure 6 plots CMAQ-simulated NOx and Maximum Daily 8-hr Average (MDA8) ozone concentrations for the different scenarios. Figures 6(a)-(d) plot absolute NOx concentrations, 6(e)-(h) differences of the future scenarios from base case, 6(i)-(l) absolute MDA8 O_3 and 6(m)-(p) differences with respect to the 2013 base case.

As expected, it is predicted in figures 6(a)-(d) that absolute NOx concentrations decrease with increasing fleet turnover, electrification, and emissions control.

For example, concentrations hotspots are predicted all over the highway loops over Houston for the BAU case which significantly decrease as we move towards the CT case. In other words, stringent emissions controls/retrofits accompanied with complete fleet turnover result in lower NOx emissions and consequently, lower NOx concentrations. However, figures 6(i)-(l) which plot ozone concentrations convey a different message. The Business as Usual case shows lowered MDA8 O_3 concentrations over the highway loops, and higher concentrations elsewhere. This can be explained by the fact that highways have significant NOx emissions and are therefore NOx-saturated. In such areas, O_3 and NOx concentrations are inversely correlated as illustrated by previous studies (e.g. Choi et al., 2012). Another interesting point in panel 6(i) illustrates increased ozone concentrations over regions northwest to the loop, due to ozone formation in the outflow of NOx-saturated areas. The outflow regions are NOx-limited and provide favorable conditions for ozone formation, as illustrated by Pan et al. (2015). With decreasing tighter controls, increased fleet turnover, and decreasing NOx concentrations, O_3 concentrations increase along the highway loop and decrease over the outflow. Similar facts are corroborated in figures 6(m)-(p), which show the effects of ozone impacts vis-à-vis the base 2013 case. It is predicted that ozone concentrations due to increased motor vehicle emissions decrease for the BAU case over the NOx-saturated areas by 1-3 ppb while increasing 1-2 ppb over the outflow. With increasing controls/turnover/retrofit and lower NOx emissions, O_3 concentrations increase by 1-2 ppb over the highways but decrease over the entire outflow surrounding the highway loop, as well as the areas enclosed by the loop. Of note is the CT case where there is a decrease of 3-4 ppb over the northwestern outflow, the same region where significant ozone increase was predicted for the BAU case.

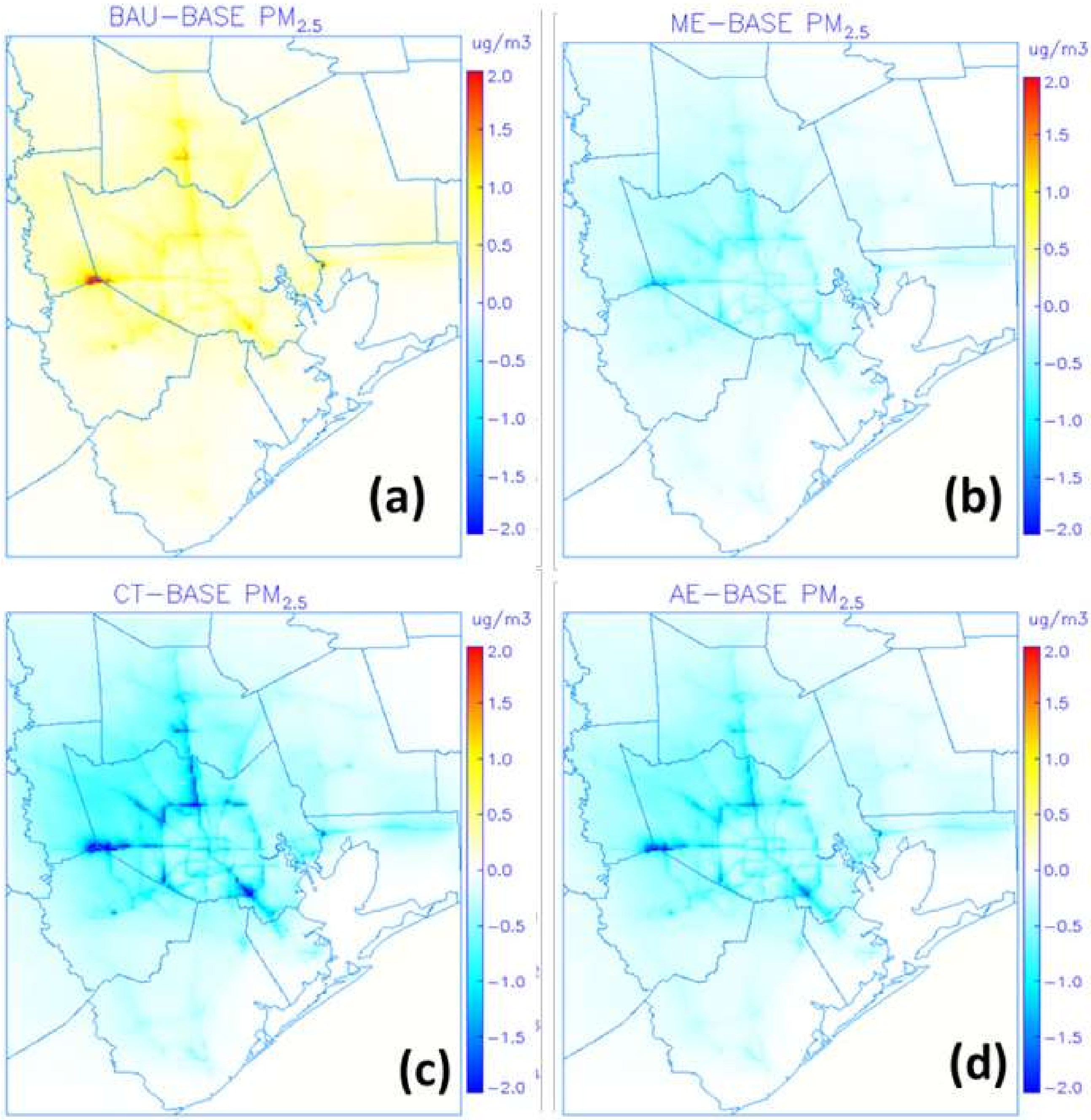


Figure 7: Spatial differences of monthly average PM2.5 surface concentrations, micrograms per meter cubed (µg/m³). (a) BAU-Business As Usual, (b) ME – Moderate Electrification, (c) AE- Aggressive Electrification, and (d) CT – Complete Turnover.

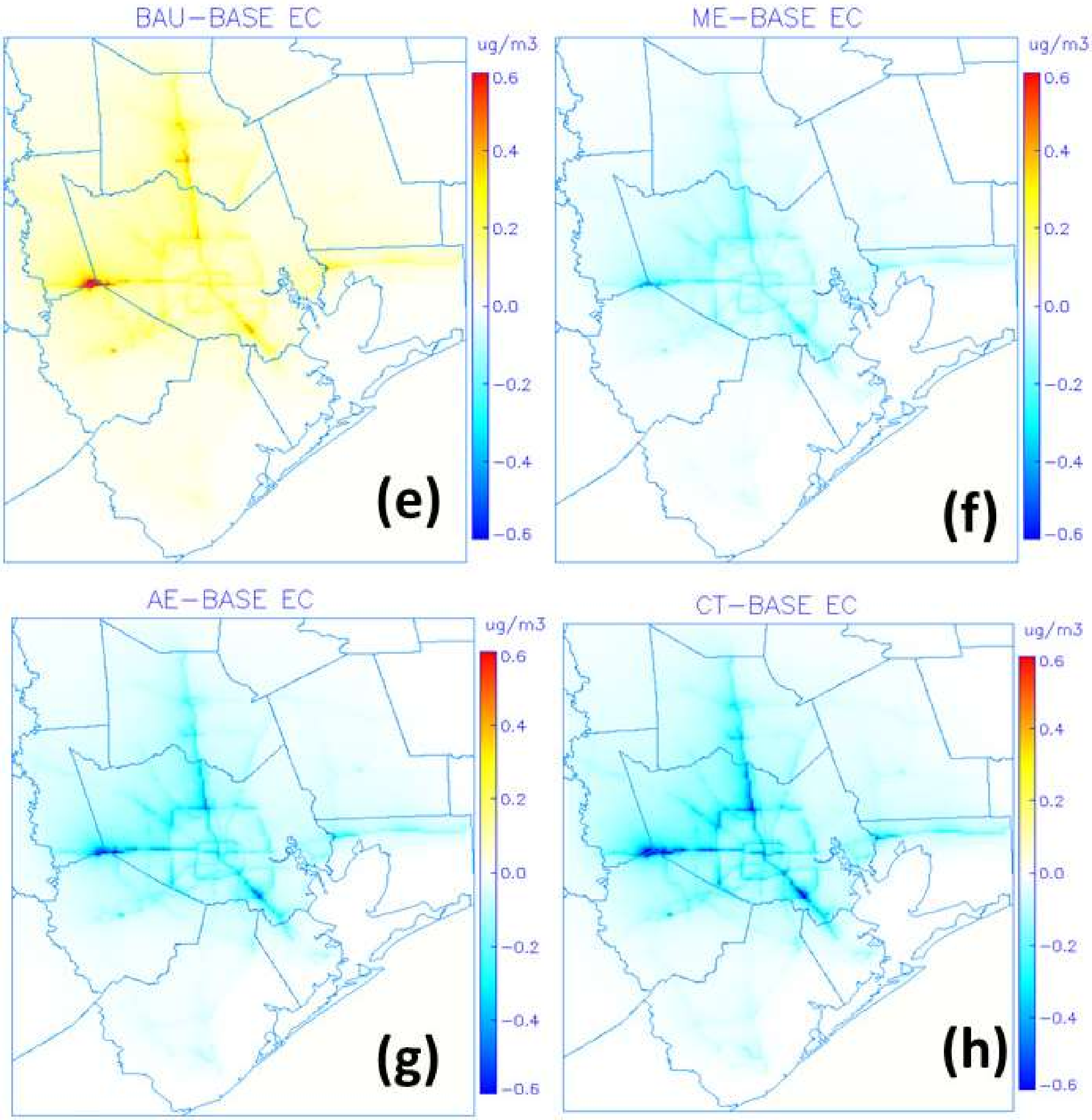


Figure 7: Spatial differences of monthly average elemental carbon surface concentrations, micrograms per meter cubed (μg/m³). (e) BAU-Business As Usual, (f) ME – Moderate Electrification, (g) AE- Aggressive Electrification, and (h) CT – Complete Turnover.

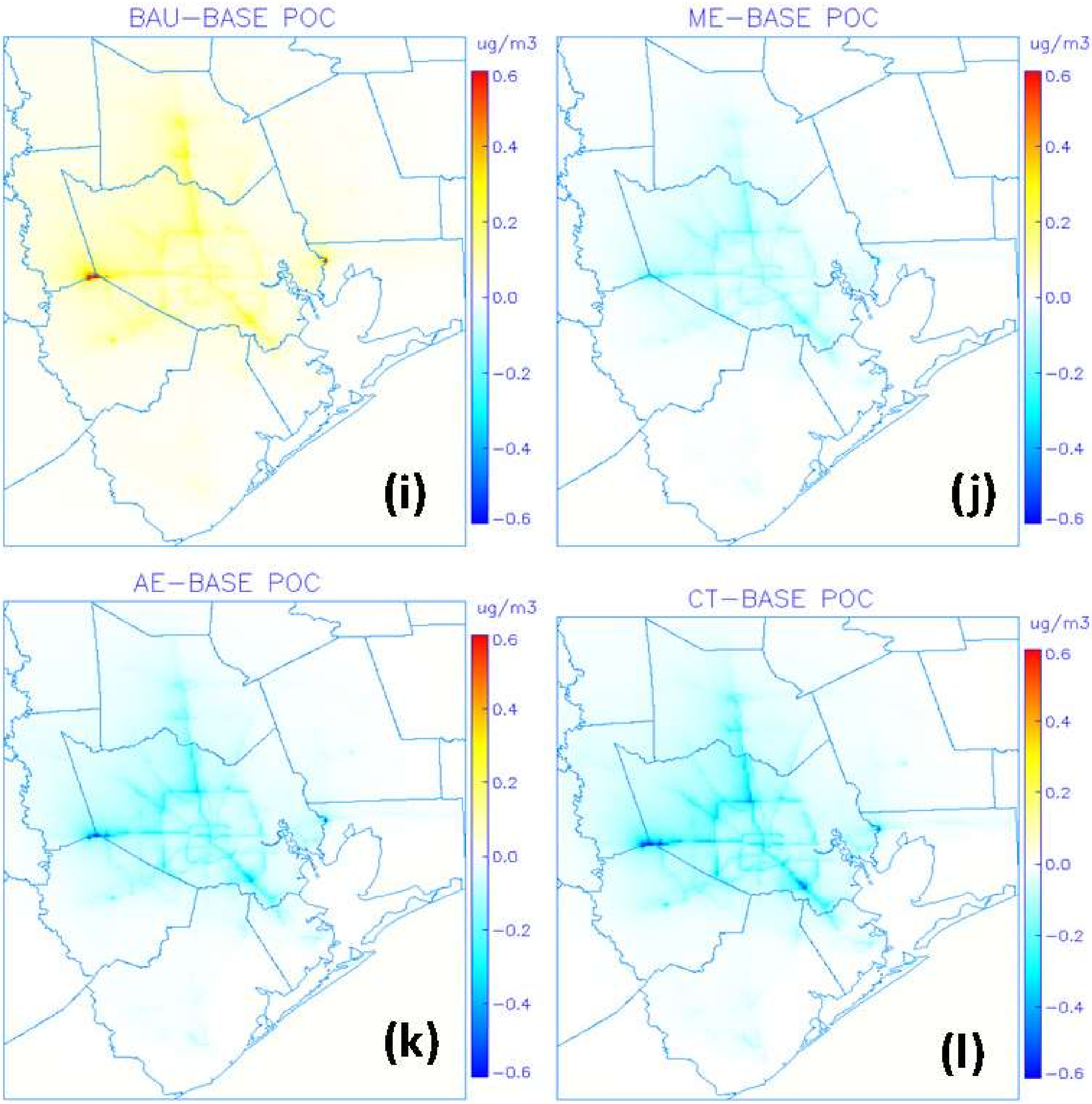


Figure 7: Spatial differences of monthly average particulate organic carbon surface concentrations, micrograms per meter cubed (µg/m³). (i) BAU-Business As Usual, (j) ME – Moderate Electrification, (k) AE- Aggressive Electrification, and (l) CT – Complete Turnover.

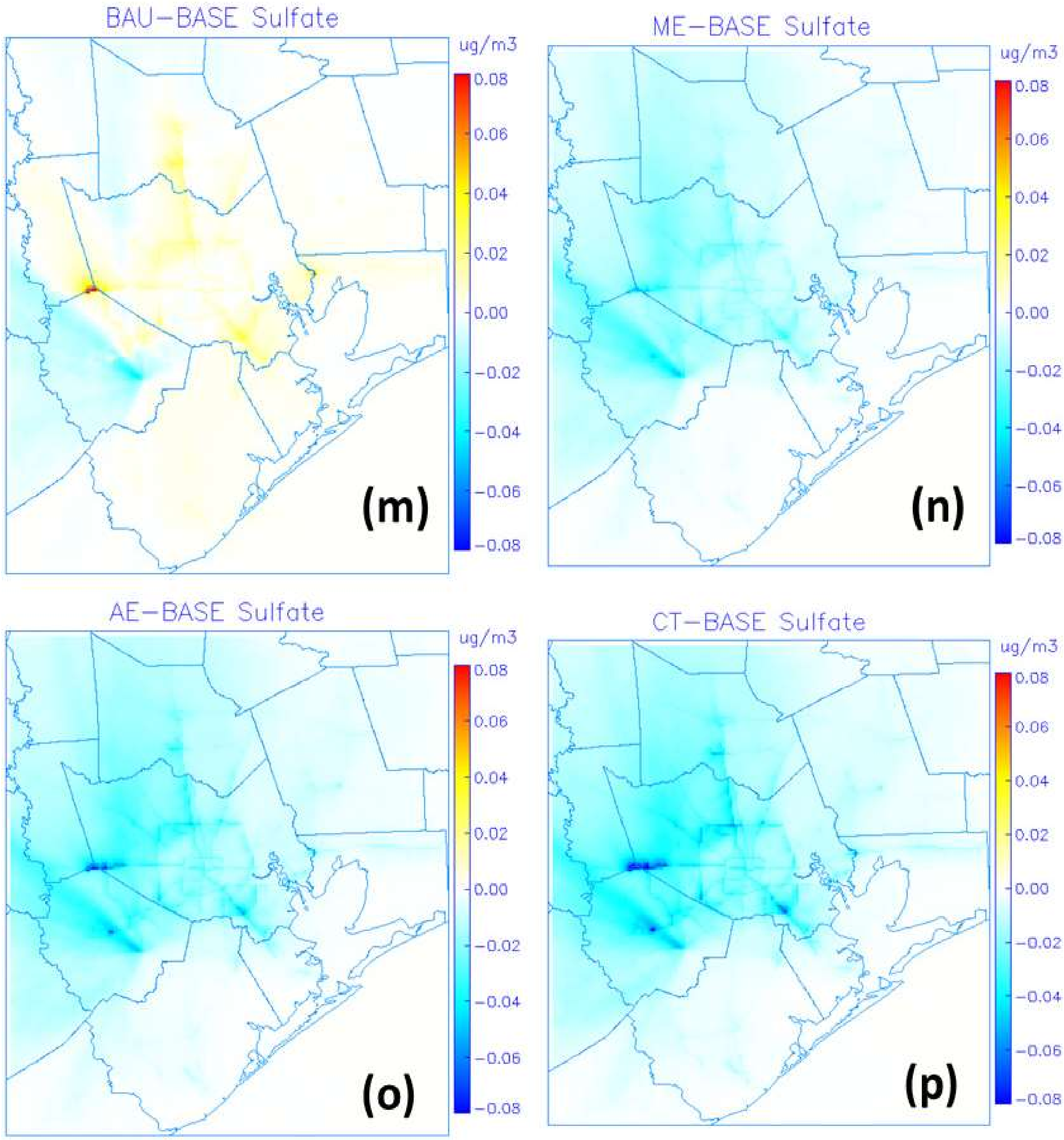
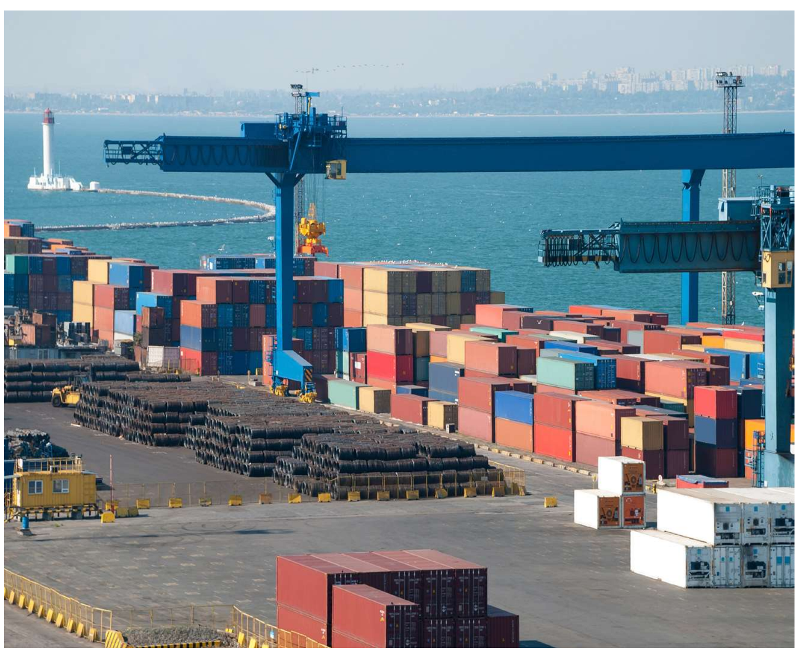


Figure 7: Spatial differences of monthly average sulfate surface concentrations, micrograms per meter cubed (μg/m³). (m) BAU-Business As Usual, (n) ME – Moderate Electrification, (o) AE- Aggressive Electrification, and (p) CT – Complete Turnover.

SPECIATED FINE PARTICULATE MATTER

Figure 7 plots the spatial differences between the projected control scenarios and the base 2013 case. The BAU case results in increasing PM2.5 concentrations by 1-2 µg/m³ (figures 7(a)-7(d)), while the control scenarios bring about changes between 0.5-2 µg/m³. The most dramatic changes occur on the highways, due to a reduction in motor vehicle emissions, as is corroborated in the plots for EC (figures 7 (e-h)) and OC (figures 7(i-l)). The changes in sulfate (figures 7 (m-p)) also mirror EC and OC, but one additional important point is the reduction in sulfate hotspots over areas with EGU emissions. This could be explained by the reduction in coal capacity over these areas.



HEALTH IMPACTS

This section presents health impacts related to the BAU, ME, AE and CT. Pollutant metrics include Maximum Daily 8-hr Average (D8HourMax) for O_3 and daily 24-hr mean (D24HourMean) for PM2.5, respectively. The USEPA's PopGrid program (U.S. EPA, 2017b) was implemented to allocate 2010 block-level U.S. Census population data to our BenMAP domain. Population information is classed into groups of race, ethnicity, genders, and age range. The BenMAP model contains county-level population growth rates for each year from 2000 through 2050.

We evaluated the health endpoint of "Mortality, All Cause" in this study. For O_3, we chose health impact functions based on the epidemiological studies by Bell et al. (2005), Zanobetti and Schwartz (2008), and Levy et al. (2005), and for PM2.5, we chose a study by Krewski et al. (2009). These studies were chosen as their analyses were based on a large geographic area (e.g., 116 U.S. cities in Krewski et al. (2009)). Hence, they are likely to be more representative and applicable to our analysis in the Houston area. Moreover, we also examined several O_3-induced morbidities (e.g., asthma exacerbation, emergency room visits) and associated benefits. Because the health impact functions for morbidities were derived from fewer cities or smaller time-scale sample sizes, the functions from several epidemiological studies were used to estimate the risk outcome.

We predict that the BAU case will result in an increased number of premature deaths with respect to 2013, but all of the control scenarios will result in prevented mortality with respect to the 2013, as illustrated in Figure 8. For PM2.5, the results indicate about 121 more premature deaths in the BAU case, and 109, 177, and 229 prevented premature deaths in the ME, AE, and CT cases, respectively. These findings coincide with trends in PM2.5 concentration, as depicted in panels (a)-(d) in Figure 7. The findings also roughly correspond to 61% enhancement of PM2.5 emissions in the BAU case, and 46%, 75%, and 95% reductions in emissions in the ME, AE, and CT cases. An interpretation of the results for O_3, however, is more complicated because the trends of O_3 change vary spatially (panels (m)-(p) of Figure 6). For instance, in the BAU case, BenMAP would predict an increase in adverse health effects in the downwind area because of increase in O_3 concentrations, while predicting a decrease of damage in the urban and major highways. In contrast, for the other scenarios with emissions reductions (i.e., the ME, AE, and CT cases), the gains in health endpoints in downwind areas are all greater than the losses over the urban highways, resulting in about 5, 11, and 17 prevented premature deaths, respectively. We may expect more health benefits if we extend the simulation domain to cover more places downwind. It should be noted that even in the case of an increase in O_3 concentrations over the urban highways, the reductions in air toxics emissions would occur, so their concentrations would lead to more health benefits. However, the health impact functions for these air toxics are not available in the current BenMAP model. The economic cost (benefit) values generally coincide with premature mortality results. Table 4 shows similar trends in O_3-induced morbidities and associated benefits. Thus, the emissions reductions scenarios would significantly reduce asthma exacerbation and school loss days, benefiting younger individuals.

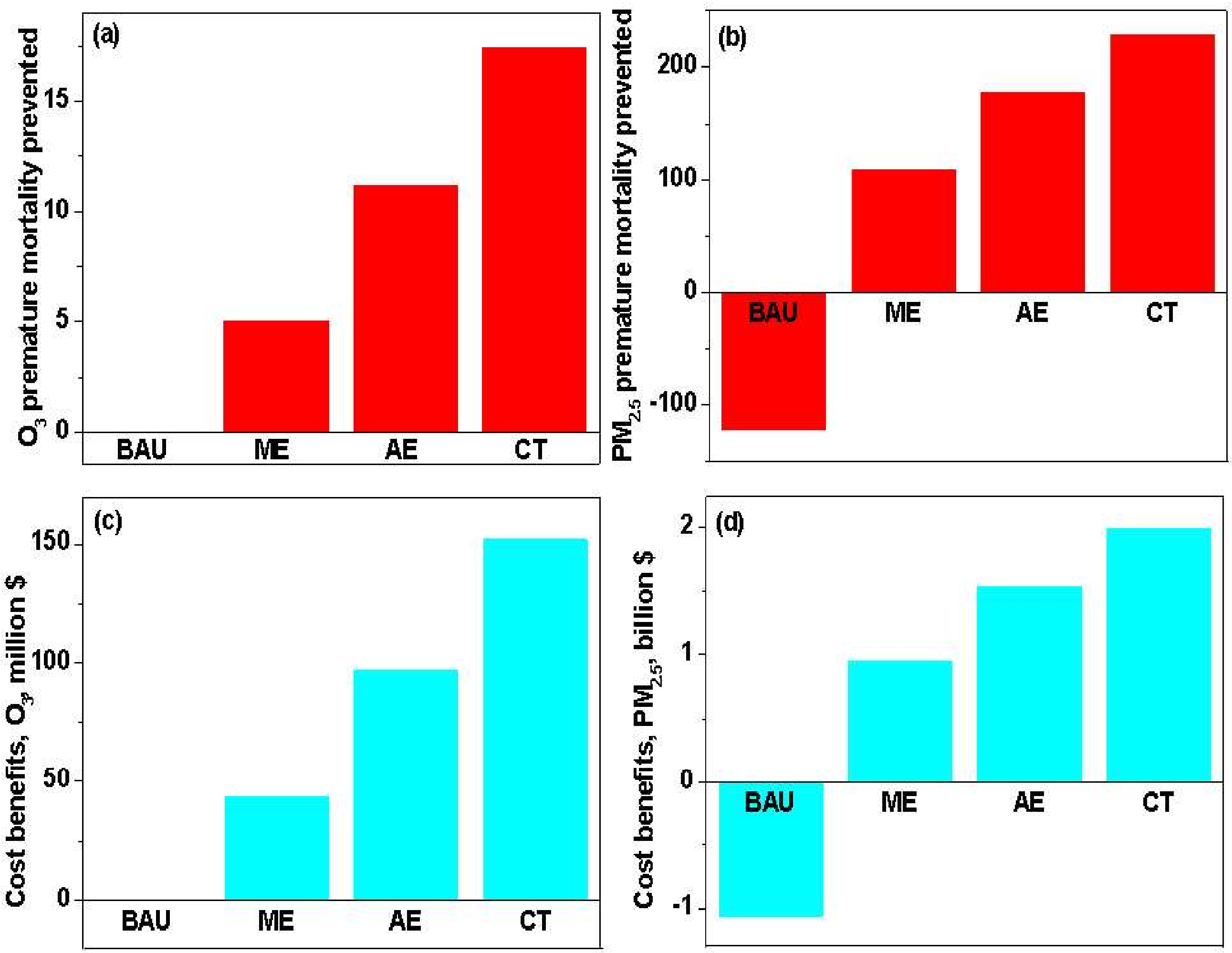


Figure 8. Estimates of avoided mortality and benefits from the changes in O_3 and PM2.5 concentrations in the 2040 scenarios. The age range is 0 to 99 for O_3 and 30 to 99 for PM2.5. In each plot, positive values indicate the number of premature deaths prevented because of control strategies and the associated benefits achieved, while the negative values in the BAU case indicate an increase in the number of premature deaths and economic losses.

Table 3: Estimates of avoided mortality and benefits from the changes in O_3 and PM2.5 concentrations in the future year scenarios. The age range is 0 to 99 for O_3 and 30 to 99 for PM2.5. Note: The BASE scenario is the baseline case (2013) in the BenMAP model, and the future year scenarios are the different control cases. Positive values indicate the number of premature deaths prevented because of control strategies and the associated benefits achieved, while the negative values in the BAU case indicate an increase in the number of premature deaths and economic losses.

Species	Scenarios	Premature Mortality Prevented	Benefits [Million Dollars, in 2015 currency year]
Ozone	Business As Usual	0.04	-0.33
	Moderate Electrification	5.01	43.57
	Aggressive Elecrtification	11.17	97.19
	Complete Turnover	17.46	151.99
PM 2.5	Business As Usual	121.53	-1057.69
	Moderate Electrification	108.92	947.99
	Aggressive Electrification	177.21	1542.27
	Complete Turnover	229	1993.07

Table 4. Estimates of prevented O_3-induced morbidities and benefits in the future year scenarios.

Scenarios	Prevented Cases of Asthma exacerbation, one or more symptoms	Benefits [Million Dollars, in 2015 currency year]
Business As Usual	-1213	-0.076
Moderate Electrification	7534	0.475
Aggressive Electrification	16119	1.016
Complete Turnover	24652	1.554
	Prevented Emergency room visits, Asthma	
Business As Usual	-1	-0.001
Moderate Electrification	20	0.01
Aggressive Electrification	43	0.023
Complete Turnover	67	0.036
	School loss days, Prevented	
Business As Usual	-833	-0.088
Moderate Electrification	5,518	0.585
Aggressive Electrification	11,844	1.255
Complete Turnover	18,153	1.924
	Prevented Hospital admissions, All respiratory	
Business As Usual	0	-0.002
Moderate Electrification	4	0.133
Aggressive Electrification	8	0.294
Complete Turnover	13	0.459

SUMMARY, CONCLUSIONS, AND FUTURE WORK

Four emissions scenarios were considered to understand the effects of future control technologies, fleet turnover and electrification for both gasoline and diesel vehicles on air quality and health impacts over the 8-county area surrounding Houston, which is in nonattainment for ozone with respect to the new EPA standard of 70 ppb. For each case, the vehicular activities (Vehicle Miles Travelled, Vehicle Population and Hoteling hours) were scaled to reflect future population increases and vehicle usage. The cases considered included Business as Usual (projected increased activity with no new controls/retrofits/fleet turnover), Moderate Electrification (35% of the fleet assumed to be electric, 33% clean combustion technologies/retrofitted and 32% current vehicles), Aggressive Electrification (70% electric, 15% clean combustion technologies and 15% current) and Complete Turnover (65% clean combustion technologies, 35% electric). These turnover assumptions were applied to aggregate emissions from both gasoline and diesel vehicles. The emissions were modeled and speciated using the Motor Vehicle Emissions Simulator and the USEPA's SPECIATE database. They were temporally and spatially allocated to a 1-km grid using the Sparse Matrix Operator Kernel Emissions model. Using a fine resolution of 1-km helped to identify NOx-saturated and NOx-sensitive areas over the simulation domain.

The Business As Usual Case represented increased emissions with no controls. Consequently, ozone concentrations along highways decreased due to NOx-titration for this case. However, it resulted in significant ozone formation in the NOx-limited outflow over the regions bordering the I-610 highway loop in Houston. The emissions control cases all resulted in ozone increases along the highways, due to decreasing saturation. However, the emissions control cases resulted in ozone reduction both in the regions enclosed by the highways as well as the outflow. Simulated PM2.5 concentrations showed elemental and organic carbon hotspots along the highways, which decreased with increasing control and fleet turnover. One important point was the removal of sulfate hotspots in 2040 due to fossil fuel retirement.

Our health impact assessments indicated that while the Business As Usual case would lead to 122 additional premature deaths, the Moderate Electrification, Aggressive Electrification, and Complete Turnover scenarios prevented 114, 188, and 246 premature deaths, respectively. Further, the prevented morbidities and economic costs (benefits) generally mirrored premature mortality. These findings can potentially shed light on the effects of mobile emissions control strategies in other urban environments. Large urban cities can benefit significantly from reductions in PM2.5 pollution if local emissions from the transportation sector are controlled, while efficient O_3 pollution reductions primarily occur in downwind areas.

One advantage over the 8-county area is the significant retirement of fossil capacity and consequent replacement by renewables as indicated by Borkar et al. (2016). This can provide an impetus to clean electrification in Texas, but these efforts might not be replicable everywhere. For example, a significant fraction of the generation in states such as Pennsylvania and Ohio is by coal, and the added load due to electrification could exacerbate an existing nonattainment problem. Hence, several scenarios need to be investigated over the continental United States to understand the overall effects of fleet electrification and long-range transport of emissions.

This study assumes the added load because of motor vehicle electrification will be borne by the upcoming renewable electricity generating capacity. This is a bounding estimate as the renewable capacity might not be adequate to meet electrification demands, a fraction of which would then be needed to transfer to the fossil capacity. Hence, electricity demand needs to be wisely allocated to minimize emissions. Another uncertainty not considered in this study is changing climate in 2040, which would invariably affect emissions and future EGU load. Further modeling and analyses needs to be conducted on these points to get a clearer picture of motor vehicle electrification with load on residual fossil capacity in the light of changing climate.

This is a pilot study to show how the combined effects of a greening grid, emissions control, and fleet electrification can improve air quality and health indicators over the 8-county area surrounding Houston. There are several studies which can offshoot from this – one being the effects of truck stop electrification being studied in detail to identify the candidate stops for electrification, which can be extended to buses (especially school buses) to reduce idling hours and hence improve fuel consumption. The additional investigation can also be done to understand expenses per mile for newer gasoline and diesel vehicle vis-à-vis electric vehicles for different combustion, emissions control and battery technologies, and amalgamated with a change in health costs due to cleaner air, to understand the total monetary benefits/disadvantages of fleet electrification for vehicle owners.

AUTHOR BIOS

Dr. Yunsoo Choi received a Ph.D. in Atmospheric Chemistry (2007) from Georgia Institute of Technology, and B.S. in Chemistry (1994) from Hanyang University (in Korea) and M.S. in Physical Chemistry from Hanyang University (1996) and in Biophysical Chemistry (1999) from University of California in Irvine (1999). His Ph.D. topic is about the Spring and Summer transitions of ozone and its precursors over North America and photochemistry over Antarctica using Regional chEmical trAnsport Model (REAM: developed by Dr. Choi and his supervisor). After graduation, he worked as a Postdoctoral Research Scientist at California Institute of Technology/Jet Propulsion Laboratory, where he worked on the evaluation of satellite retrieval products. In February 2010, he joined NOAA Air Resource Laboratory as a staff scientist, where he worked on developing chemical and physical modules of Air Quality Forecasting system. After he shortly worked for NASA OMI satellite team for April-August of 2012 and joined the University of Houston as an assistant professor since the fall semester of 2012 and is an associate professor at the Department of Earth and Atmospheric Sciences of UH now. Over the period at UH, with his group members, he has established UH Air Quality Forecasting (UH-AQF) system to provide 48 hour forecasting results for ozone and particulate matters (PM) and their ingredients for local users, atmospheric scientists and air pollution policymakers including diverse end-users of the forecasting system (see the details, http://spock.geosc.uh.edu). He also initiated several Artificial Intelligence machine learning projects for diverse atmospheric sciences such as air quality forecasting, climate change (and future energy usage) and air pollution, energy land mapping for renewable energy, extracting surface air pollution data from remote sensing, and forecasting Hurricane's track and strength. His UH research group was/is working on diverse projects on atmospheric chemistry, air pollution, climate change, and disaster relief funded by the university, non-governmental, state, federal and overseas organizations.

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